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POTENTIAL BIOLOGICAL EFFECTS OF HYPOTHETICAL OIL DISCHARGES IN THE ATLANTIC COAST AND GULF OF ALASKA

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REPORT TO COUNCIL ON ENVIRONMENTAL QUALITY

Massachusetts Institute of Technology

Cambridge, Massachusetts 02139

Report No. MITSG 74-19
April 1, 1974

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Administrative Statement

As a follow-up to the original Georges Bank Petroleum Study on the environmental and economic effects of regional offshore oil development, Stephen F. Moore, Gary R. Chirlin, Charles J. Puccia, and Bradley P. Schrader, from M.I.T.'s Department of Civil Engineering, have analyzed the specific biological consequences of hypothetical oil discharges from 22 drilling sites on the Atlantic and Alaskan offshore continental shelves and from 3 nearshore Atlantic terminal sites. The ecological risks from offshore accidental oil spills on Georges Bank and the Southern Baltimore Canyon are lower than for those in the Gulf of Alaska and the Georgia Embayment. All nearshore oil spills would entail high environmental risk, and accidental spills at the terminal sites might cause environmental changes detectable for 3 to 10 years afterward. The authors have provided the Council on Environmental Quality not only a comprehensive survey of the effect oil spillage might have on the organisms and habitats of the ocean and coastal zone, but also significant data and qualitative predictions necessary for evaluating the environmental impact of offshore oil development.

The M.I.T. Sea Grant Program has organized the printing and distribution of this report under the Sea Grant project established to disseminate important studies and research results developed at M.I.T. under other than Sea Grant support. Funds to do this came in part from a grant by the Council on Environmental Quality, the National Sea Grant Program and in part from the Massachusetts Institute of Technology.

Ira Dyer
Director

April, 1974

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ACKNOWLEDGEMENTS

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Chapter 1

Summary

This report is an analysis of the primary biological effects of potential oil discharges resulting from hypothetical oil production activity on the Atlantic/Alaskan OCS. The results are intended for input to the Council on Environmental Quality as part of the information base to decide: 1) whether or not to recommend OCS oil exploration/drilling in these areas; and 2) if yes, where.

Although emphasis is placed on analysis of impacts and recovery from large-volume infrequent accidental oil spills, small volume continuous discharges of hydrocarbons are also considered. Effects of oil releases from offshore platforms and spills occurring at coastal terminals are assessed.

This study does not yield quantitative predictions of environmental impacts of oil discharges. Available data are too sparse for such predictions to be reliable, especially quantification of population/community level effects of oil. However, qualitative predictions are attempted which are rough order of magnitude estimates of physical, chemical and biological changes likely to occur due to oil releases into the marine environment. These predictions cannot be extensively verified without additional field data. An attempt is made to identify regional differences, which are relevant to pending OCS petroleum resource development decisions. Regional differences of interest include: 1) oil spill probabilities; 2) physical environmental characteristics--spill trajectories and the fate of oil in marine subsystems; and 3) biological factors relevant to oil effects. This report deals specifically with biological factors. An additional objective of this study is an improved definition of research needs relating to oil discharge impacts.

The study consists of several principal parts: 1) an environmental inventory; 2) summary of response and sensitivity of individual organisms to petroleum substances; 3) analysis of population/community level responses to oil, especially population recovery from accidental spills; and 4) assessment of potential effects of specific oil discharges associated with hypothetical OCS petroleum developments.

Environmental inventories for four distinct marine sub-regions of the Atlantic/Alaskan OCS have been prepared by sub-cnntractors. The Research Institute of the Gulf of Maine (TRIGOM) in conjunction with the University of Rhode Island (URI) prepared descriptions of two regions: Bay of Fundy to Cape Cod and Cape Cod to Sandy Hook, N.J. The Virginia Institute of Marine Science (VIMS) prepared a description of the region from Sandy Hook to Cape Canaveral, Florida. The University of Alaska compiled environmental data for the Gulf of Alaska.

Information assembled by sub-contractors for Atlantic sub-regions consists of several types. Each sub-region is subdivided according to habitats--marine subsystems characterized by similar physical/chemical variables such as temperature, salinity and sediment type and which contain a characteristic assemblage of species. Examples of habitats are rocky shores, worm and clam flats, offshore bottoms and pelagic areas. Each occurrence of a habitat is assumed to be physically, chemically and biologically identical within an environmental region. Of all species associated with each habitat a subset of five to twenty species is selected from each habitat for detailed population analysis. These species are selected because of their importance for any one of many reasons including knowledge of life history, scientific interest, ecological role or dominance, commercial value, recreational value, endangered status, etc. The set of selected species are not considered unique and especially they are not considered necessarily sufficient to describe the actual community dynamics of a habitat. They merely represent a manageable subset of species for analysis of population level effects of oil spills. For each selected species data have ben sought describing intraspecific characteristics (fecundity, mortality, larval life-style, etc.) and interspecific characteristics (competitors, predators, food, etc.). Habitats for the Gulf of Alaska cannot be characterized or even identified because of lack of basic environmental data. Therefore, the Gulf of Alaska is treated throughout this report separately as a special case. In general, little biological analysis can be carried out concerning effects of oil spills in the Gulf of Alaska.

Although the environmental inventories constitute impressive volumes of information, the data is typically incomplete, sparse, and uncertain. In particular, and most importantly, significant gaps exist in life history information for selected species. For more than 40% of the selected species fundamental data on fecundity, survivorship and larval life-style is not available.

In general, effects of accidental spills are divided into initial impacts and population/community recovery. Initial impacts depend on the oil exposure--amount, composition and distribution--and on the response and sensitivity of individual organisms to the exposure. Recovery is the result of complex dynamic processes by which the system returns toward an ecological "equilibrium," following initial impacts.

Because several extensive reviews of literature on effects of oil on individual organisms have been reported in the past two years, no attempt has been made to carry out another comprehensive review. Rather, results of reviews previously conducted at M.I.T. are updated and modified to conform to the study at hand. However, considerable effort is made herein to analyze the essential problem of assessing population level effects.

Effects of oil on individuals are categorized as: 1) lethal toxic effects due primarily to soluble aromatic hydrocarbons (boiling point<250°C); 2) sub-lethal toxic effects from soluble aromatics; 3) coating of birds, mammals and inter- and sub-tidal sessile species with oil; 4) alteration of substrates by oil, which makes habitats uninhabitable for normally found species; and 5) incorporation of hydrocarbons into organism tissues causing tainting or accumulation of potential carcinogens. Insufficient data exist to identify sensitivity of each selected species to each of these effects. Based on a modification of a previous review of literature it is hypothesized that exposure of adult marine organisms to 1-100 ppm soluble aromatics for a few hours can be lethal. Concentrations as low as 0.1 ppm may be lethal to larval stages. Such concentrations are expected to result from oil slicks less than one to two days old, that is, unweathered. It is assumed that coating of inter-tidal areas with the main body of a slick (weathered or unweathered) will kill most sessile species. Although the amount of oil necessary to exclude benthic species from their substrates is largely unknown, this is one of the most important effects of oil spills because of the potentially long persistence times (of the order of years) of oil in sediments. Sublethal toxic effects of oil, in particular interference with chemical cues, causing disruption of feeding, reproduction or other essential life sustaining activities, may result from concentrations of soluble aromatics as low as 10 ppb. Tainting and hydrocarbon accumulation in organism lipid pools probably occurs in virtually all marine species due to either chemical equilibration with ambient water quality or food chain accumulation. Analysis of population level implications of sub-lethal effects and incorporation phenomena is virtually impossible given the present lack of understanding of governing phenomena. However, these effects of oil must be recognized as potentially important environmental impacts.

Recovery from oil spills, although difficult to define, consists of degradation and natural removal of oil from exposed areas followed by return of populations and communities. Persistence of oil in various habitats depends on the physical variables controlling degradation processes--evaporation, dissolution, microbial oxidation and chemical/photo-oxidation. Available nutrients, light, temperature, substrate particle size and water velocities are identified as the most important physical variables controlling degradation processes, but functional relationships describing degradation rates are not available. Therefore, estimates of persistence of oil in habitats are made empirically by inference from data reported for specific spills including: West Falmouth, Santa Barbara, *Tampico Maru*, Tanker *Arrow*, San Francisco, and *Torrey Canyon*. The results allow some differentiation among habitats, but are not definitive. In general, oil deposited in unconsolidated, fine sediments can remain chemically and/or physically insulting to the environment for at least four years and as long as ten years or more. In rocky substrates oil may be naturally removed in as little as two years. Although differences in persistence of oil in marine habitats likely varies between biogeographical regions due to differences primarily in temperature and sunlight, the magnitude of these differences has not been identified from the data. It is hypothesized that oil in Northern habitats may persist for time periods longer than in Southern habitats, other factors being equal.

Definition of biological recovery is highly subjective, depending on one's point-of-view. In the case of 100% mortality in a habitat, return to a specified density and/or stable age distribution are selected as definitions of recovery herein. Little can be said in the case of partial mortality situations, because there is no way of specifying the distribution of mortalities among age groups.

Analysis of biological recovery of a population (assuming a physically and chemically suitable habitat) must account for intraspecific characteristics (fecundity, survivorship, etc.) and interspecific relationships (competition, predation, etc.). Much of the data necessary to include all of these facets of the problem is unknown. However, as a working hypothesis, four broad classes of recovery strategies are identified based on different modes of colonization and expansion in unsettled, hospitable habitats. Species can be classified according to recovery strategies from even sketchy life history descriptions. Recovery analysis for each class is considered separately and applied to all species within each class. The four classes and corresponding biological recovery time estimates in unsettled, hospitable habitats are: 1) wide-dispersal-ubiquitous immigrants (a majority of marine species), recovery time is estimated to be of the order of longevity (life span); 2) wide-dispersal-non-ubiquitous (some birds), recovery time is unknown, but this strategy is extremely vulnerable to unexpected adult mortality; 3) non-wide-dispersal (*Spartina* spp.; some amphipods, polychaetes and gastropods), recovery time is unknown but longevity is a lower bound; and 4) pelagic species (fish and plankton), only species demonstrating highly localized, discrete "breeding populations," e.g., some anadromous fish, are considered potentially vulnerable, but the significance of any threat is indeterminate.

This analysis of recovery is only a first approximation and does not consider many potentially important aspects of the problem. Phenomena such as explosive "blooms," successional prerequisites and overgrazing are not well enough understood to model. An organism's niche is always assumed available for repopulation. Gaining a foothold to initiate recovery is not considered a problem. The results, therefore, must be accepted with due caution.

Each selected species in each habitat in each biogeographical region is classified by recovery strategy. However, the large data gaps and lack of inclusion of interspecific relations, prevent the coalescence of the species recovery time estimates to obtain habitat recovery time estimates. Therefore, habitats are not differentiated intra- or inter-regionally according to biological recovery time in unsettled, hospitable habitats from 100% mortality due to an oil spill.

Although differentiation of biological recovery times among habitats is not possible, initial-impact and recovery are used to attempt to assess effects of oil spills associated with hypothetical OCS developments. Impact on pelagic areas, offshore bottoms and nearshore habitats are evaluated for spills originating from several hypothetical offshore drilling sites in the Atlantic OCS and Gulf of Alaska. In general, spills originating from hypothetical Atlantic offshore platforms are not expected to cause significant biological damage in terms of population level effects. Localized deposition of weathered patches of oil or tar balls on rocky or sandy shores is likely. Where deposited such oil may persist for two years or more depending on the type of intertidal habitat impacted. Because of the paucity of data for Gulf of Alaska, conclusions regarding biological effects of oil spills in this region are even more difficult to draw.

The biological significance of continuous discharges from oil-water separators or other sources of chronic discharges of hydrocarbons remains obscure. It is recommended that discharges of this type be prevented until a more definitive analysis can be made.

Spills originating nearshore—at terminals--can be expected, in all cases considered, to come ashore within 0-2 days and cause high rates of mortality to most species exposed. Heavy oiling of substrates is expected and physical/chemical recovery is likely to take at least 2-3 years in hard substrates and five, ten or more years in fine, unconsolidated sediments. Subsequent biological recovery can be expected to take many years at best.

Based on the analysis of hypothetical discharges of oil, it is concluded that hypothetical drilling sites EDS 6, 7, 8 and 9 in the Baltimore Trough and hypothetical drilling sites EDS 1, 2, 3 and 4 on Georges Bank are least vulnerable to environmental impacts of oil. EDS 5 south of Long Island, New York and EDS 10, 11, 12 and 13 in the Georgia Embayment pose relatively higher environmental risks due to probability of oil slicks reaching shore within 3-5 days or less. Little is concluded from this study one way or another, regarding hypothetical drilling sites in the Gulf of Alaska.

CHAPTER 2

OBJECTIVES AND SCOPE OF ANALYSIS

2.1 Problem Statement

A decision to allow exploration and development of potential petroleum resources in the outer continental shelf (OCS) of the U.S. Atlantic coast and Gulf of Alaska depends in part on potential biological effects resulting from such development activities. A problem of particular interest is the potential impacts of oil discharges originating from offshore platforms, transshipment activities and nearshore terminals. The principal objective of this report is to assess as clearly as possible from available data the potential biological consequences of such hypothetical oil discharges. In addition to drawing conclusions regarding potential biological impacts of certain hypothetical oil discharges, this report also recommends several areas of research considered necessary to refine the analysis presented here.

The scope of this study is constrained to consider only certain hypothetical discharges of crude oil into marine environments. Specifically, three categories of discharges are analyzed: 1) infrequent, accidental oil spills originating from thirteen hypothetical drilling sites in the Atlantic OCS (see Figure 2-1) and nine hypothetical drilling sites in the Gulf of Alaska (see Figure 2-2); 2) continuous discharges from hypothetical offshore platforms of oil-water separator effluents containing low concentrations of petroleum hydrocarbons; and 3) infrequent, accidental oil spills occurring at hypothetical nearshore terminal facilities (Buzzard's Bay, Massachusetts; Delaware; Charleston Harbor, South Carolina). Hypothetical drilling sites and terminal locations were specified for analysis by CEQ. Analysis of probability, size, trajectory and behavior of oil spills considered herein

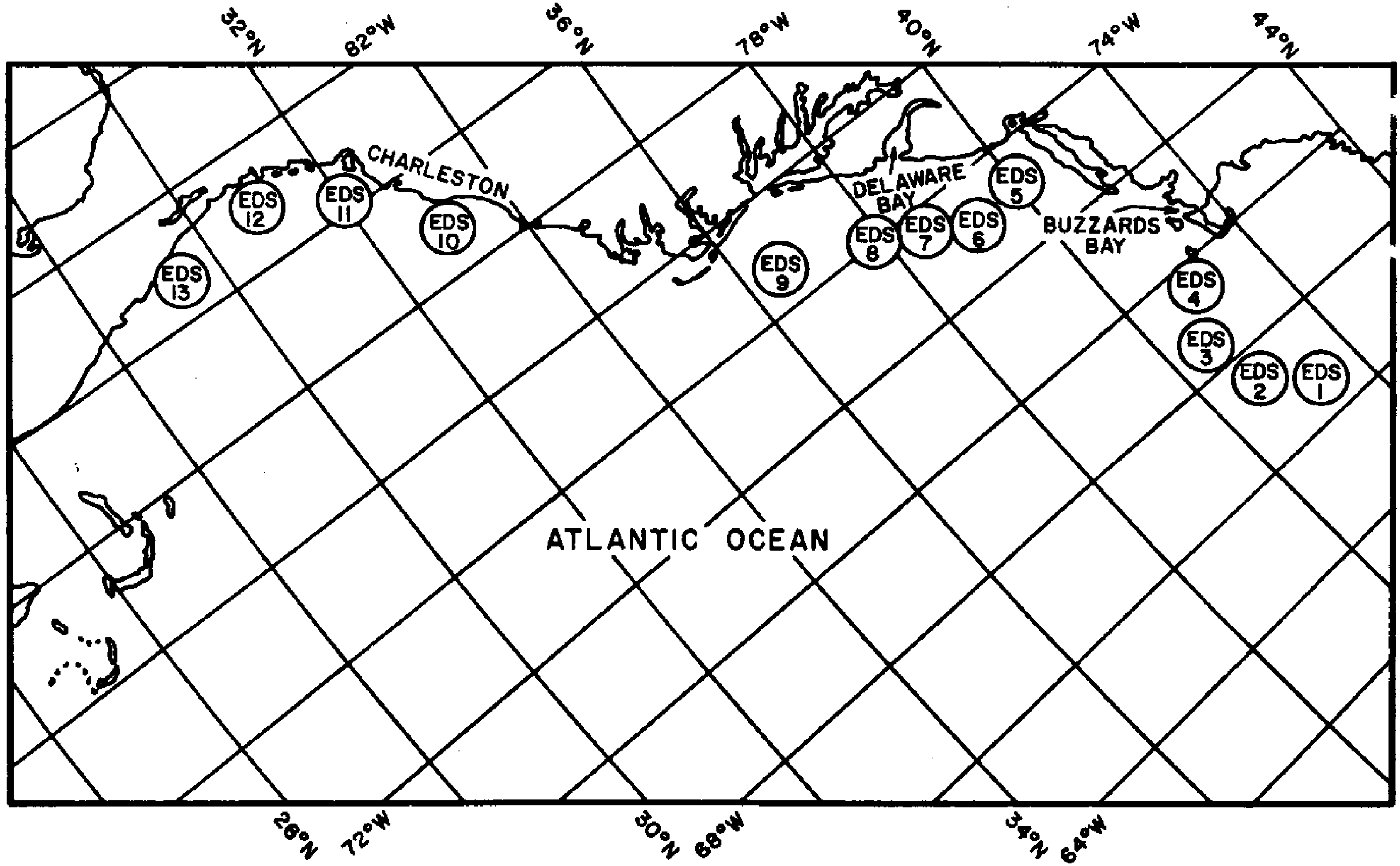

FIG. 2.1 LOCATION OF THE THIRTEEN HYPOTHESIZED EASTCOAST DRILLING SITES (EDS) AND THE THREE TERMINAL AREAS INVESTIGATED.

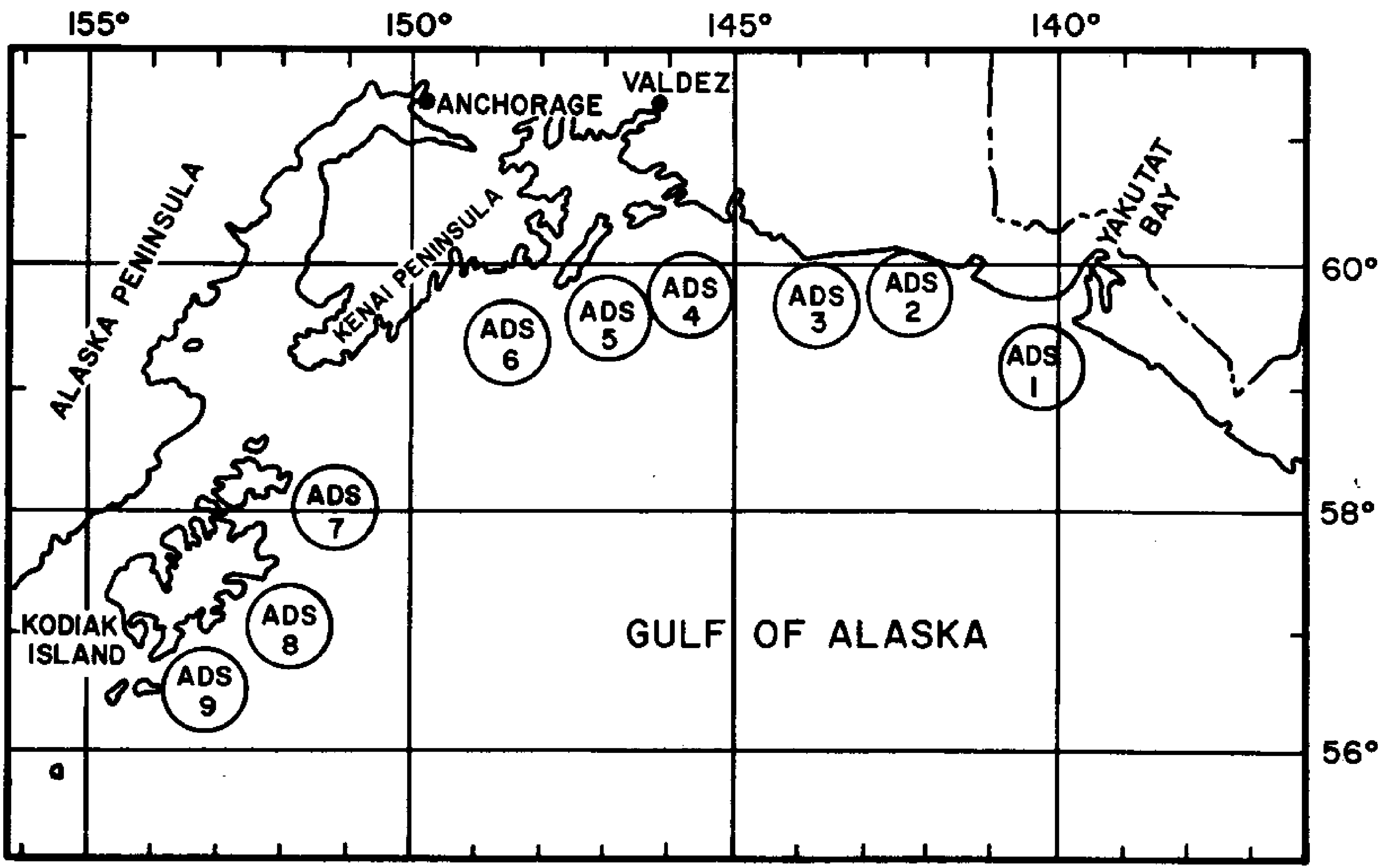

FIG. 2.2 LOCATION OF THE NINE HYPOTHESIZED GULF OF ALASKA DRILLING SITES (ADS).

are reported in Stewart, et al. (1974). No consideration is given in this report to impacts of "secondary" environmental changes, such as refinery effluents.

This study is confined to an analysis of the biological effects of the specific discharges outlined above within the framework of available data. No new experimental or field data has been collected or sought. Environmental inventories of the study region have been prepared by sub-contractors, as discussed in Chapter 4. Compilation of data regarding effects of oil on marine environments is a principal task of the study reported herein.

2.2 Report Organization

The framework of analysis for this study is presented in Chapter 3, including a discussion of limitations of the analysis and available data. Information compiled by sub-contractors describing the biota of the study region is summarized in Chapter 4. Relevant chemical characteristics of crude oil and persistence of oil in marine environments (weathering) are discussed in Chapter 5. Responses and sensitivity of individual marine organisms are analyzed in Chapter 6. Chapter 7 presents a general analysis of population and community effects of oil discharges, especially accidental spills. The results of analyses presented in Chapters 5, 6 and 7 are combined with specific hypothetical oil discharge scenarios in Chapter 8 and biological impacts of these representative scenarios are assessed. Conclusions drawn from the study are summarized in Chapter 9, including recommendations for research. References are presented as the last section of each individual chapter.

2.3 References

Stewart R.J., Devanney J.W., and Briggs W. (1974) Oil Spill Trajectory Studies for Atlantic Coast and Gulf of Alaska, report to Council on Environemntal Quality, Washington, D.C., March 1, 1974, Department of Ocean Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts

CHAPTER 3

FRAMEWORK FOR ANALYSIS

An overall framework, basic assumptions and methods of analysis for the Atlantic/Alaskan OCS petroleum study are described in this chapter. Understanding of material presented in ensuing chapters may rely on definitions, explanations and justification discussed here.

3.1 Nature of the Problem

The ultimate objective of an analysis of this type is to predict with an acceptable degree of reliability the absolute effects of oil spills resulting from various hypothetical OCS petroleum developments. From the results of such an analysis one could directly determine a ranking, based on a particular set of criteria, of the environmental vulnerability of various regions to the specified activities. In lieu of having such definitive predictions of absolute effects it is still desirable, and a principal objective, to lay out as well as possible regional differences that do exist, even qualitatively, which may suggest relative regional vulnerability.

In general, three sets of variables can be identified which may provide a basis for identifying such differences:

1. probability of spills
2. physical characteristics of alternative regions
    a. spill trajectories: where oil goes and how fast
    b. persistence and ultimate fate of oil in the environment
3. biological factors: individual responses and sensitivities to oil and population/community recovery following exposure to oil

Wherever significant regional differences can be identified relative to these variables, a basis exists for making a decision. On the other hand, if differences are not identified, this is not to say they do not exist and one must proceed with caution accordingly. In any case, an overriding consideration throughout this analysis is an attempt to specify whether or not differences exist. This report is concerned with analysis of points 2b and 3.

No claim is made that the analysis undertaken during this project answers definitively the question: "What are the biological impacts of oil spills occurring in the Atlantic/Alaskan OCS?" The available data simply do not allow a comprehensive answer to the question. In fact, it can be argued that any apparent attempt to systematically answer this question would hide the true nature of the situation and be irresponsibly misleading. That is, such an analysis implies that the problem is understood sufficiently well to warrant an attempt to answer the question, when, in fact so many basic requisite facts are unknown that even in the best of all possible worlds there is no way of knowing if the results of the analysis are valid or not.

Although the above attitude is not subscribed to by the authors, an attempt has been made to maintain a healthy awareness and respect for the uncertainties that do exist. Hence, a principal objective of the analysis is to indicate what is known and what is not, and thereby point out the information base upon which any decision is made. It is anticipated that by at least asking the proper questions, formulation of a model can begin, directing one's attention to available data needs. From the available data and numerous assumptions a synthesis of information regarding oil spill impacts is made leading to a set of conclusions which may guide ensuing decisions. Where possible, assumptions are made using a large range of parameter values and emphasis is placed on "worst case" analysis, i.e., conditions which can be surmised to yield the greatest environmental effects. In any case, the results represent order of magnitude estimates.

3.2 Modeling the Atlantic/Alaskan OCS Environment

One of the most difficult problems to deal with is the sheer magnitude of the study. Spatially the study area includes a vast expanse of widely varying marine environments. Temporally these environments change physically, biologically and chemically with periods ranging from hours and days to decades or more. In order to reduce the problem to a manageable level, the Atlantic/Alaskan OCS is discretized at several organizational levels (described below) down to individual species. A few selected populations are analyzed in as much detail as possible.

Four sub-regions of the Atlantic/Alaskan OCS are identified and further subdivided into habitats. Habitat, as conceived herein, is defined as a subsystem of the marine environment which can be characterized by certain similar physical/chemical variables such as sediment type and salinity and which contains a characteristic assemblage of populations or community. Examples are the rocky shore, salt marsh and pelagic habitats (or subsystems). It is assumed that each habitat type is physically and biologically uniform wherever it occurs within each sub-region. For each habitat type in each sub-region, a subset of species selected from all species associated with the habitat is identified for further analysis. It is not assumed that the selected species are sufficient to account for community level dynamics in each habitat or are necessarily ecologically dominant or "key". Species may be selected for analysis for any number of reasons, including scientific importance, commercial/recreational interest, ecological dominance, endangered or unique species status and well-known status.

The habitat approach is a useful environmental discretization for analyzing the effects of oil spills in the Atlantic OCS. First, the relationships between oil and various physical factors are essential aspects of the effects of oil. Habitats provide a focal point for differentiating physical factors. Second, although the community of organisms associated with various types of habitats are not strictly uniform and, in fact, may be widely variable, many important assemblages can be delimited according to habitats, with special cases noted where appropriate. Third, the definition of habitat communities may assist in identification of species which should be selected for population level analysis. Finally, the analysis of oil spills can be keyed to habitats and intra- and inter-subregional differences may be more easily identified.

3.2.1 Population Analysis

An important feature of the analysis is the treatment of populations. Several reasons exist for using populations as the basic element of analysis (Paulik, 1971). From an analytical point-of-view, a population is a manageable unit for which some dynamic models exist of both density and age-structure. In addition, man's attention is most often directed towards the health of a population--commercial and recreation fisheries, endangered species, bird watching, etc. As a result, most biological data is centered on species level information. However, analysis of population interactions--communities--cannot be ignored. No population can be fully understood without analysis of the community in which it lives. Unfortunately, the number of populations in any marine community is overwhelmingly large and the complexity of their interactions poorly understood. As a first approximation for dealing with community dynamics, interspecific relationships thought to control recovery processes for selected species are only qualitatively analyzed. Although this approach tends to overlook some of the most important features of ecosystem dynamics, it is interesting to note that entomologists and fisheries biologists have typically relied on population models which emphasize the life history of single species (see, for example, Watt, 1968).

An alternative approach, not adopted here is to attempt to develop community or ecosystem level models of energy flow and nutrient cycling (see, for example, Odum, 1971). Typically, such models represent energy or mass transfers between grossly defined trophic levels, e.g., phytoplankton, zooplankton, fish, benthic invertebrates, etc. In theory, a set of such models representive of appropriate sub-regions and/or habitats could be developed. However, even if large scale ecosystem models of some type could be structured and necessary parameter values estimated, such an approach is of questionable value. Most importantly, responses of individual organisms and population/community recovery processes are an essential feature of oil spill effects and therefore population level models are necessary for assessment of effects. Ecosystem models do not attempt to, nor can they, represent population level phenomena at the species level.

An obviously important step in the analysis described above is the selection of species. It is unlikely that any two persons would independently arrive at the same list of selected species for a particular habitat. However, criteria such as ecological role in habitat, commercial value, recreational value, endangered status (locally or globally), well studied and scientific interest or value are all valid bases for selecting species for analysis. Therefore, virtually any reason for being important is considered acceptable for including a species on a selected list.

The actual selected species lists used in this study were provided by sub-contractors who developed the basic environmental inventories of sub-regions. The criteria leading to selected species recommendations by each sub-contractor were only broadly outlined as above. Insufficient time was available to provide the three sub-contractors an opportunity to closely interact and further refine the basis for species selection.

3.3 Assessing Effects of Oil

Moore, et al. (1973) have previously described a general framework for assessing the impacts of oil discharges into the marine environment. Five basic processes which contribute to environmental changes are illustrated in Figure 3-1. They are: inputs, transport and dispersion, biological effects and ultimate fate.

Inputs must be characterized according to amount, location, temporal distribution and chemical form. Impacts of infrequent massive inputs (spills) are likely to differ from low-concentration, continuous discharges.

Transport and dispersion processes by physical, chemical and biological agents determine the ultimate extent and intensity of exposure to contaminants. In the case of oil, weathering processes which alter the chemical composition of spilled oil during transport are particularly important. Biological transfers and modifications may profoundly alter the nature of oil by either bio-transformation (metabolism) or accumulation and storage within the lipid fraction of an organism.

Primary focus of impact assessment is biological effects, at several levels. Specific actions of a pollutant occur on individual organisms, but the effects are cascaded throughout a community by resulting changes in populations.

Ultimate fate of substances depends largely on biodegradability. Most constituents of oil in aerobic environments are ultimately degraded to CO_2, but rates of degradation vary widely due to variations in chemical structure and composition.

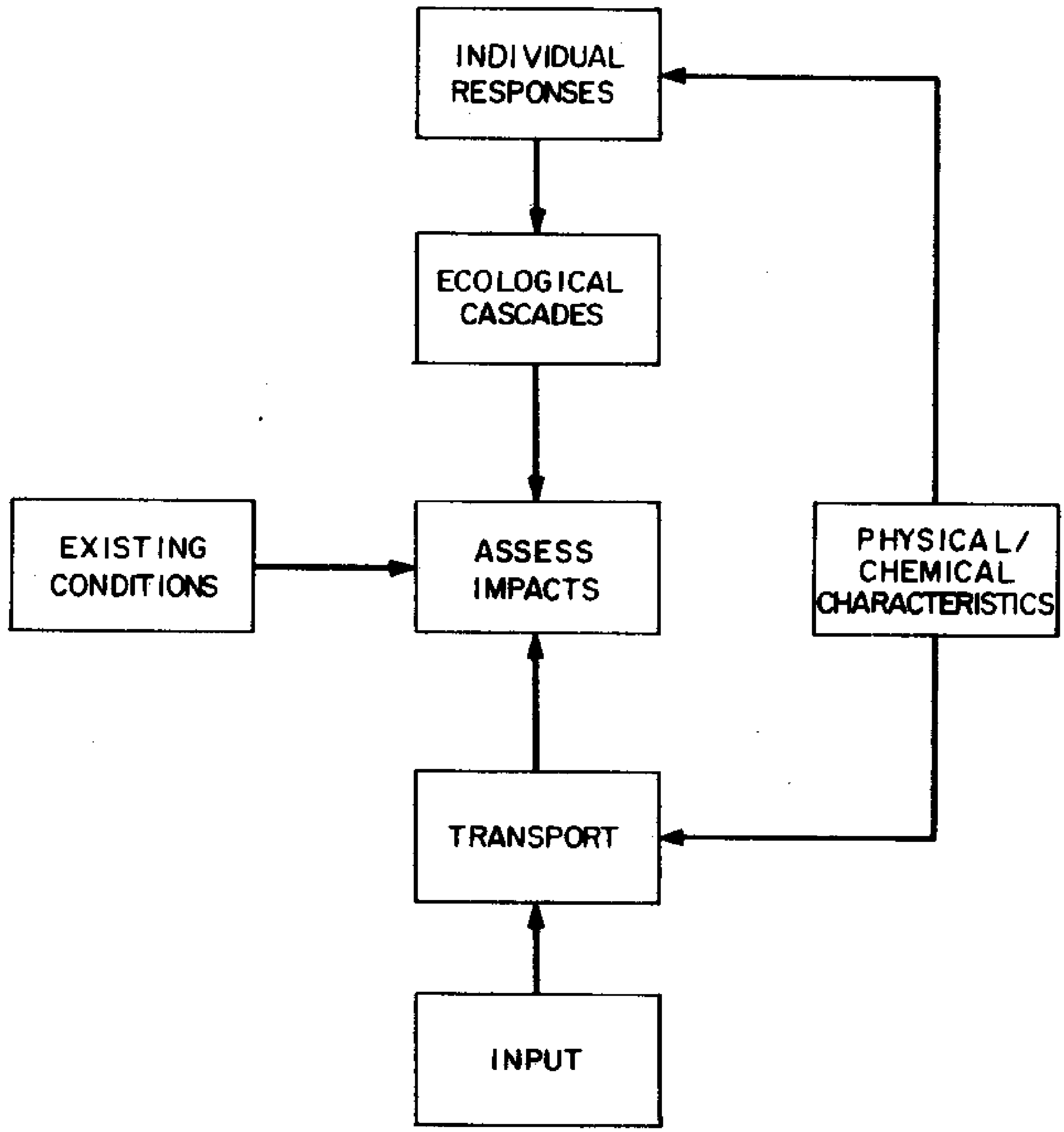

FIGURE 3-1 INFORMATION REQUIREMENTS FOR ENVIRONMENTAL IMPACT ASSESSMENT (from Moore, et. al., 1973).

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This report is concerned primarily with biological effects and ultimate fates of accidental and chronic discharges of oil resulting from hypothetical OCS petroleum developments. Input characteristics are either specified by CEQ or assumed. Spill trajectories and transport associated with this analysis are described by Stewart, Devanney and Briggs (1974).

3.3.1 Accidental Spills

Effects of accidental oil spills are divided into two parts: 1) initial impacts; and 2) recovery. Initial impacts are the actual perturbations of physical/chemical and biological variables in an environment. Recovery is the dynamic process of returning to the pre-spill "equilibirum" following initial impacts. Both physical/chemical and biological recovery must be included in the analysis. Initial biological impacts depend primarily on sensitivity of the individual organisms and the composition and amount of oil to which they are exposed. Therefore an important step in the analysis is to identify critical concentrations of petroleum hydrocarbons. Population response and recovery depend on both intra-specific factors--life history parameters such as age specific mortality, natality, migration and growth, and on inter-specific factors--community relations such as competition and predation. Community dynamics are not treated in detail. Interspecific relationships for selected species known or hypothesized to play an important role in recovery are noted, but their implications are not analyzed extensively.

3.3.2 Continuous (Chronic) Discharges

For the particular problem of assessing the population effects of relatively continuous, low concentration discharges (chronic effects) a model is most desirable but probably most difficult to develop. The problem in this case is to estimate relatively long-term (many generations) effects of subtle changes in birth and death rates because massive mortalities from direct lethal toxicity do not occur. Even with estimates of sensitivities to low level concentrations (less than that causing direct lethal toxicity), it may be virtually impossible to separate out population changes occurring due to oil discharges from those caused by natural fluctuations such as temperature and salinity.

3.4 References

Moore S.F., R.L. Dwyer and A.M. Katz (1973) A Preliminary Assessment of the Environmental Vulnerability of Machias Bay, Maine to Oil Supertankers, TR #162 Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics, Massachusetts Institute of Technology, Cambridge, Massachusetts.

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CHAPTER 4

SUMMARY OF ENVIRONMENTAL DESCRIPTION OF ATLANTIC/ALASKAN OCS

4.1 Basic Approach

Section 3.2 establishes the framework used in this report to describe the Atlantic OCS. The present chapter describes the specific sub-regions, habitats, and selected species for the Atlantic OCS. Lack of data prohibits applying this framework to the Alaskan OCS. The Gulf of Alaska is treated separately and a more qualitative subjective environmental description and analysis is carried out for this region.

There exists a vast amount of knowledge (small relative to the data needs) relevant to an environmental description of the Atlantic OCS. In order to most efficiently translate this knowledge into the framework used in this report, the task of collecting and organizing all relevant data was sub-contracted to marine biological consulting groups. Each consulting group has a working knowledge of the species in its particular region of the Atlantic OCS and a knowledge of the relevant literature. Inclusion of the biological expertise of the consulting scientists is essential to ensuring that this study is as accurate, up-to-date, and complete as possible. At the time of preparation of the present report, documents prepared by the consultants are relatively voluminous, internal, draft manuscripts not yet prepared for formal publication. The nature and amount of data compiled by the sub-contractors is summarized in following sections of this chapter. Readers interested in the specific data prepared may contact the sub-contractors directly (see TRIGOM, 1973; VIMS, 1973; U of A, 1973).

4.1.1 Sub-Regions

The entire Atlantic/Alaskan OCS is divided into four sub-regions:

1) Bay of Fundy to Cape Cod

2) Cape Cod to Sandy Hook

3) Sandy Hook to Cape Canaveral

4) Gulf of Alaska

Consultants providing environmental descriptions of these areas area as follows:

1) Regions 1 and 2 - The Research Institute of the Gulf of Maine (TRIGOM), and the University of Rhode Island (URI--under contract to TRIGOM)

2) Region 3 - The Virginia Institute of Marine Science (VIMS)

3) Gulf of Alaska - The University of Alaska (U. of A.)

4.1.2 Habitat Descriptions

Descriptions of habitats provided by consultants include the following information (where available);

1. Definition

2. Environmental Factors - characteristic physical and/or chemical factors

3. Plant and Animal Relationships - general description of the organization of the biota, including dominant populations or food pathways

4. Food Web Diagram - only a rough estimate, highlighting major types of organisms at each trophic level and including example species

5. Selected Species - selected from expanded species list (selection criteria discussed in Section 3.2 of this report)

6. Expanded Species List - (incomplete) lists of species known to occur in habitat from which selected species are identified

7. Distribution of Habitat - map depicting occurrence of habitat in region.

4.1.3 Selected Species Descriptions

The consultants also provide information on important aspects of the life histories of selected species:

1) Larval life style - pelagic, demersal, time to metamorphosis, etc.
2) Fecundity - within range
3) Natural mortality rates of larvae, juveniles, and adults
4) Growth rate
5) Maximum densities of local population - variability
6) Chemical cues are used for spawning, feeding or migration
7) Spawning area
8) Spawning seasons, times, duration, age of first spawning
9) Spawning behavior if known including any information on control of time of spawning
10) Population distribution (range) of mobile species and routes of migratory species
11) Major food species - for selected species
12) Major parasites and/or major commensals (on which the selected species depends)
13) Major predators
14) Major competitors

4.1.4 Incompleteness of Data

The magnitude of the data compilation problem and the time frame of the study (nine months) has resulted in incomplete habitat and life history descriptions in most cases. Habitat descriptions are relatively complete, although expanded species lists have not been compiled in most cases, and food web diagrams are not available in a few instances (see Table 4-1 for a tabulation of work completed on habitat descriptions). On the other hand, the life history information on selected species contains large gaps. For more than 40% of the selected species the most fundamental information on fecundity, survivorship, and larval life-style is not available (compiled from TRIGOM, 1973; VIMS, 1973).

4.2 North Atlantic Sub-Regions

In the presentation to follow, some habitats have the same definition in all three sub-regions. This does not imply that the organisms are the same between habitats--only that the general physical/chemical conditions and the basic community structures are similar.

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TABLE 4-1 WORK COMPLETED ON HABITAT DESCRIPTIONS[1]

% of Habitats in Region with Information

Sub-Region	Definition	Plant/Animal Relationships Environmental Factors	Food Web Diagram	Selected Species	Expanded Species List	Distribution of Habitat
Bay of Fundy to Cape Cod	100%	90%	75%	90%	40%	100%
Cape Cod to Sandy Hook	100%	100%	50%	100%	30%	100%
Sandy Hook to Cape Canaveral	100%	90%	70%	90%	0	100%

[1] Summarized from sub-contractor reports (TRIGOM, 1973; VIMS, 1973)

4.2.1 Bay of Fundy to Cape Cod (TRIGOM)

The following habitats are identified in this region:

1) Pelagic system - including estuary (inland), coastal and open gulf
2) Offshore bottom
3) Rocky shores - exposed and protected
4) Sand beach/shore
5) Salt marsh
6) Oyster - mussel reef
7) Worm - clam flat
8) Shallow salt pond

The plankton based pelagic habitat includes small plants and animals found in the water column excluding adult fishes which are treated elsewhere. There are four general groupings: phytoplankton, holoplankton (zooplankton which are pelagic throughout their life cycle), meroplankton (usually larval forms or eggs of benthic invertebrates or fishes which are only temporarily pelagic), and tychoplankton (usually benthic or epibenthic invertebrates which swim up into the water column temporarily, usually at night). Three general sub-habitats are recognized; 1) the open ocean community existing over the Gulf of Maine and the banks rimming it; 2) the coastal community in the water derived by mixing of open ocean water with that from behind the headlands, and 3) inland water behind the headland and extending shoreward to the $0.5^{0}/00$ isopleth.

The offshore bottom habitat is by far the most extensive, comprising an area greater than all other habitats combined (except the Pelagic habitat), with a variety of substrates probably equalling all the littoral habitats collectively, and greater than any one of them. The species can be generally classified into two categories: those that burrow into the substrate, and those that live on the substrate. It is customary to consider as epifauna those organisms that attach to or live on hard substrate (rock, shell, timber, etc.) only; those associated with the sediment, even those which rest on its surface, are for convenience classed as infauna.

Rocky shores include intertidal and subtidal rock formations such as headlands, rocky ledges, outcroppings, boulders and pilings to the limit of the seaweeds. Two major sub-habitats are included with separate species lists: 1) biota associated with rocky shores and headlands exposed to wave stress, and 2) hard substrates, pilings and rock outcroppings inside of headlands and estuaries.

Sandy shores grade from beaches at the shoreline to subtidal areas of sandy substrate down to the limit of both effective light penetration for photosynthesis and effective wave action (ca. 20 m). The communities change with depth of water. The beach area here includes the backshore to the sublittoral bar and trough system in the surf area.

Salt marshes are defined as wetlands where the emergent vegetation is composed of salt-tolerant grasses. Features also include salt pans, tidal creeks and the subtidal areas of soft mud adjacent to the grass areas, referred to as potholes in Maine. Salt marshes occur in protected waters where mud deposition causes sufficient shoaling to allow colonization by grasses with subsequent accumulation of peat substrate. The flora, fauna and ecology of salt ponds is similar to salt marshes, particularly to subtidal potholes, but will be treated as a separate habitat because of their abundance and size in many coastal areas from Cape Cod South through New York and New Jersey.

Mussel reefs are intertidal and subtidal communities based on and dominated by beds of mussels. They may overlap with the rocky shore community or be found among mud flat communities where a preliminary source of attachment (such as a small rock or boulder) has allowed initial settlement.

Worm and clam flats are characterized by accumulations of silt and clay which, in the intertidal areas, form a low-profile zone of particles sorted with fine fractions in the upper zone. The substrate can be quite sandy and hence overlap with the beach-sandy bottom category. Worm and clam flats are always in protected embayments or estuaries where wave action is not severe enough to disrupt the characteristic faunal assemblages.

Salt ponds are shallow lagoon areas formed behind barrier beaches which are flushed regularly with the tide. They are characterized by seasonal shifts in the sediment. Intertidal flats are not common but often tidal deltas form at the inlets. The shallow salt pond is rare in the northern region and no reliable data exists. One pond was described. (See the habitat description for region south of Cape Cod, section 4.2.2).

Table 4-2 lists the selected species for each habitat in the region north of Cape Cod. Extended species lists are available only for rocky shore, mussel reef and offshore bottom habitats; lists of important species are available for the other habitats (TRIGOM, 1973).

4.2.2 Cape Cod to Sandy Hook (URI)

The following habitats are found in this region:

1) Pelagic system--including inland, coastal, offshore areas, and migratory species
2) Offshore bottom
3) Rocky shore
4) Sand shore

TABLE 4-2 Selected Species for Bay of Fundy to Cape Cod

PELAGIC

Ceratium spp.	dinoflagellate
Chaetoceros spp.	diatom
Thalassiosira spp.	diatom
Pleurobrachia pileus	ctenophore
Calanus finmarchicus	copepod
Pseudocalanus minutus	copepod
Oithona similis	copepod
Microsetella norvegica	copepod
Eucheata norvegica	copepod
Acartia spp.	copepod
Tortanus discaudatus	copepod
Evadne nordmanni	cladoceran
Meganyctiphanes norvegica	euphausid shrimp
Sagitta elegans	arroworm
Limacina retroversa	sea butterfly
Polychaete, mollusca, and decapod larvae	
Fish larvae	
Clupea harengus	herring
Merluccius bilinearis	silver hake
Salmo salar	atlantic salmon
Plautus alle	dovekie
Rissa tridactyla	kittiwake

OFFSHORE BOTTOM

Aurelia aurita	coelenterate
Nepthys incisa	polychaete worm
Nucula proxima	clam
Arctica islandica	mahogany quahog
Spisula solidissima	surf clam
Placopecten magellanicus	sea scallop
Ampelisca vadorum	amphipod
Homarus americanus	lobster
Pandulus borealis	northern shrimp
Ophiura robusta	brittle star
Gadus morhua	cod
Pseudopleuronectes americanus	winter flounder

ROCKY SHORE

Ascophyllum nodosum	rock-weed algae
Laminaria spp.	kelp
Metridium dianthus	sea anemone
Thais lapillus	dog whelk
Mytilis edulis	mussel
Littorina littorea	periwinkle
Balanus balanoides	barnacle
Homarus americanus	lobster
Strongylocentrotus droebachiensis	sea urchin
Somateria spectabilis	eider duck

TABLE 4-2 (Cont'd)

SAND SHORE	
Nephthys caeca	sand worm
Tellina agilis	clam
Spisula solidissima	surf clam
Pagurus longicarpus	hermit crab
Haustorius canadensis	amphipod
Echinarachnius parma	sand dollar
Ammodytes americanus	sand launce
WORM and CLAM FLAT	
Nereis virens	sand worm
Arenicola marina	lugworm
Streblospio benedicti	polychaete worm
Glycera dibranchiata	blood worm
Mya arenaria	soft clam
Polynices heros	snail
Nassarius obsoletus	snail
Macoma balthica	clam
Mercenaria mercenaria	quahog or hard clam
Corophium volutator	amphipod
Crangon septemspinosus	mud shrimp
Limulus polyphemus	horseshoe crab
MUSSEL REEFS	
Harmothoe imbricata	polychaete worm
Harmothoe extenuata	polychaete worm
Crassostrea virginica	virginia oyster
Mytilus edulis	edible mussel
Crepidula fornicata	slipper shell
Asterias vulgaris	starfish
Asterias forbesi	starfish
SALT MARSH	
Spartina alterniflora	marsh grass
Clymenella torquata	polychaete worm
Melampus bidentatus	snail
Orchestiidae	amphipod
Crangon septemspinosus	mud shrimp
Diptera larvae	
(*Aedes sollicitans*)	mosquitoes
(*Chironomus* spp.)	flies
Fundulus heteroclitus	mummichog
Pseudopleuronectes americanus	winter flounder
Ammospiza leconteü	sharptail-sparrow

5) Salt marsh
6) Salt pond
7) Worm and clam flats

The definitions of the pelagic system, offshore bottom, rocky shore, worm and clam flats, and salt marsh habitats in this region are the same as in the region north of Cape Cod (section 4.2.1).

A salt pond is a shallow embayment formed by a barrier beach which separates it from open coastal water. Frequently, there is a permanent or semi-permanent inlet which permits tidal exchange. The ponds are variable in size, ranging from a few acres to over a thousand acres. They vary in depth from one to four meters, the maximum usually being in the vicinity of a channel. Seasonal shifts in the sediment in these ponds sometimes produce tidal deltas which may close the inlet. In some ponds the inlets are maintained by the construction of rock jetties or by frequent dredging. Rivers, streams and ground water flow into the ponds producing variable salinity conditions. The quantity of fresh water and the frequency of tidal exchange determines the salinity levels of these embayments, which in turn influences the composition of the plant and animal communities. The bottom sediments include regions of sand, gravel, mud and clay. Salt marshes are often located in close association either within or at the periphery of the ponds.

Table 4-3 lists the selected species for the region Sandy Hook to Cape Cod. Extended species lists are available for the pelagic system and salt pond; lists of important species are available for rocky shore and salt marsh habitats (TRIGOM, 1973).

TABLE 4-3 Selected Species for
Cape Cod to Sandy Hook

PELAGIC-INLAND

Skeletonema costatum	diatom
Thalassiosira spp.	diatom
Chaetoceros spp.	diatom
Acartia spp.	copepod
Pseudocalanus minutus	copepod
Oithona spp.	copepod
Fish larvae	
Menidia menidia	silversides
Alosa pseudoharengus	alewife
Osmerus mordax	american smelt
Branta bernicla	brant
Melanitta deglandi	white-winged scoter
Aytha marila	greater scaup
Larus argentatus	herring gull

-COASTAL

Skeletonema costatum	diatom
Leptocylindrus spp.	diatom
Nitzschia spp.	diatom
Oithona spp.	copepod
Acartia spp.	copepod
Centropages spp.	copepod
Brevoortia tyrannus	menhaden
Clupea harengus	herring
Pelecanus occidentalis	brown pelican

-OFFSHORE

Skeletonema costatum	diatom
Chaetoceros spp.	diatom
Thalassionema nitzschiodes	diatom
Calanus finmarchicus	copepod
Centropages typicus	copepod
Pseudocalanus minutus	copepod
Sagitta elegans	arrow worm
Stenotomus chrysops	scup
Scomber scombrus	mackerel
Morone saxatilis	striped bass
Pomatomus saltatrix	bluefish
Thunnus thynnus	bluefin
Oceanites oceanicus	Wilson's petrel
Balaenoptera musculus	blue whale
Balaena glacialis	right whale
Mégaptera novaeangliae	humpback whale
Balaenoptera physalus	fin whale

TABLE 4-3 (Cont'd)

-MIGRATORY	
Pomatomous saltarix	bluefish
Morone saxatilis	striped bass
Thunnus thynnus	bluefin
OFFSHORE BOTTOM	
Cerianthiopsis americanus	anemone
Nephthys incisa	polychaete worm
Pherusa affinis	polychaete worm
Ampharetid spp.	polychaete worm
Nucula proxima	clam
Tellina agilis	clam
Ampelisca vadorum	amphipod
Leptocheirus pinguis	amphipod
Cancer spp.	crab
Paralichthys dentatus	summer flounder
Limanda ferruginea	yellowtail flounder
Pseudopleuronectes americanus	winter flounder
Pollachius virens	pollack
Gadus morhua	cod
Merluccius bilinearis	silver hake
Urophycis chuss	squirrel or red hake
Melanogrammus aeglefinus	haddock
Peprillus tricanthus	butterfish
ROCKY SHORE	
Fucus spp.	algae
Ascophyllum nodosum	rock week
Laminaria sp.	kelp
Mytilis edulis	mussel
Littorina littorea	periwinkle
Thais lapillus	dog whelk
Balanus balanoides	barnacle
Cancer borealis	jonah crab
Homarus americanus	lobster
Asterias forbesi	starfish
Arbacia punctulata	sea urchin
Tautogolabrus adspersus	cunner
Tautoga onitis	tautog
Larus argentatus	herring gull
Halichoerus grypus	grey seal

TABLE 4-3 (Cont'd)

SAND SHORE

Ammodytes americanus	sand launce
Sterna hirundo	common tern
Numenius borealis	eskimo curlew
Passerculus princeps	ipswich sparrow
Halichoerus grypus	grey seal

SALT MARSH

Spartina alterniflora	marsh grass
Modiolus demissus	ribbed mussel
Littorina littorea	periwinkle
Melampus bidentatus	snail
Carcinus maenas	green crab
Uca pugnax and *pugilator*	fiddler crabs
Orchestia palustris	beach hopper
Fundulus heteroclitus	mummichog
Pseudopleuronectes americanus	winter flounder
Menidia menidia	silversides
Agelaius phoeniceus phoeniceus	eastern red-winged blackbird
Pandion haliaetus	osprey
Anas rubripes	black duck
Melanitta deglandi	white-winged scoter
Larus argentatus	herring gull
Ondatra zibethica	muskrat
Microtus pennsylvanicus provectus	meadow vole

SALT POND

Zostera marina	eel grass
Ruppia maritima	aquatic angiosperm
Ulva lactuca	sea lettuce
Skeletonema costatum	diatom
Chaetoceros spp.	diatom
Acartia clausi	copepod
Nereis virens	sand worm
Gemma gemma	gem clam/pea clam
Crassostrea virginica	virginian oyster
Mercenaria mercenaria	hard clam/quahog
Mya arenaria	soft clam
Spisula solidissima	surf clam
Nassarius obsoletus	snail
Pagurus longicarpus	hermit crab
Callinectes sapidus	blue crab
Menidia menidia	silversides
Fundulus heteroclitus	mummichog
Pseudopleuronectes americanus	winter flounder
Aythya marila	greater scaup
Anas rubripes	black duck
Melanitta deglandi	white-winged scoter
Pandion haliaetus	osprey
Larus argentatus	herring gull

TABLE 4-3 (Cont'd)

WORM and CLAM FLATS

Pectinaria gouldii	trumpet worm
Clymenella torquata	polychaete worm
Mercenaria mercenaria	quahog/hard clam
Ensis directus	razor clam

4.3 Mid- and South Atlantic Sub-Region (VIMS)

The following habitats are found in this composite region:

1) High energy beach
2) Marsh (salt)
3) Oyster reef
4) Worm and clam flats
5) Grass bottom systems
6) Oligohaline system (0.5-5.0%)
7) Medium salinity plankton system (Mesohaline) (5-18%)
8) Coastal system
9) Neutral embayments

The high energy beach, worm and clam flat and salt marsh habitats are defined here the same as in the region north of Cape Cod (section 4.2.1).

Oyster grounds, reefs or "rocks" occur in abundance in the shallow embayments of the coast from New Jersey to Florida. Such reefs may occur subtidally. Oysters developing on soft bottoms gradually convert the area into a firm substrate of shells as numbers accumulate. These reefs thus provide substrate for a wide variety of benthic organisms, including algae, sponges, cnidarians, flatworms, nemerteans, bryozoans, polychaetes, other mollusks, crustaceans and tunicates. The fauna and flora associated with a given oyster reef depends in large part upon salinity, with those of higher salinities having a greater number of species represented.

Grass bottom systems are intertidal and shallow subtidal communities based on and dominated by beds of eelgrass *(Zostera marina)*. These systems are eurythermal and euryhaline, and occur primarily in sheltered areas having a mud or sand-mud bottom. Eelgrass provides substrate and shelter for a rich and varied biota, the beds thus comprising a complex epibenthic community.

Oligohaline waters are defined as those having a salinity of 5 to 0.5 0/00. The unidirectional flow of water in the limnetic zone changes to slow circulation in the oligohaline regime, and the waters are characteristically turbid. Oligohaline systems are subjected to sudden fluctuations in salinity due to varying fresh water influxes.

The medium salinity plankton system or mesohaline system encompasses the 5-18 0/00 salinity zone or mid-estuary. Geographical delimitation of the zone is impossible because the zones may shift depending upon such factors as tidal cycles, volume of river flow, precipitation, evaporation, and variations in salt water intrusion. This category is not restricted to plankton and might better be termed a mesohaline system. However, planktonic organisms constitute the dominant biomass of the mid-estuary and form the base of the food web. The coastal system covers the coast from littoral waters to the edge of the continental shelf.

Neutral embayments are partially enclosed coastal environments receiving negligible river drainage. In the neutral embayment, precipitation approximates evaporation, sedimentation rates are low, salinity is relatively constant, and seasonal biotic variations are complex. Species diversity is typically high and composed largely of marine organisms. Water temperature, light, and nutrients are considered to be the primary factors of ecological significance in the temperate zone. Neutral embayments have received very little attention; no detailed studies have been made on such environments in the region from Sandy Hook to Cape Canaveral. Reliable species lists and food web summaries are thus impossible to compile for this region.

Table 4-4 lists the selected species for the joint mid- and south Atlantic region. Very short lists of some additional important species in each habitat are available (VIMS, 1973).

TABLE 4-4 Selected Species
Sandy Hook to Cape Canaveral

HIGH ENERGY BEACH	
Donax variabiles	coquina clam
Spisula solidissima	surf clam
Emerita talpoida	sand mole crab
Ocypode quadrata	ghost crab
Amphiporeia spp.	amphipod
MARSH	
Spartina alterniflora	marsh grass
Spartina patens	cord grass
Juncus gerardi	black grass
Juncus roemerianus	needle rush
Modiolus demissus	ribbed mussel
Prokelisia marginata	plant hopper
Orchelimum fidicinum	salt marsh grasshopper
Uca spp.	fiddler crabs
OYSTER REEF	
Cliona spp.	boring sponge
Diadumene leucolena	anemone
Polydora spp.	polychaete worm
Crassostrea virginica	virginian oyster
Urosalpinx cinerea	oyster drill
WORM and CLAM FLAT	
Clymenella torquata	polychaete worm
Diopatra cuprea	polychaete worm
Mercenaria mercenaria	hard clam/quahog
Mya arenaria	soft clam
Rangia cuneata	clam
GRASS BOTTOM SYSTEMS	
Zostera marina	eel grass
Paracerceis caudata	isopod
Bittium spp.	snail
Aequipecten irradians	bay scallop
Crepidula convexa	slippershell

TABLE 4-4 (Cont'd)

OLIGOHALINE SYSTEMS	
Spartina spp.	grasses
Rangia cuneata	clam
Neomysis americana	oppossum shrimp
Trinectes maculatus	hog choaker
Micropogon undulatus	croaker
Leiostomus xanthurus	spot
Cynoscion regalis	gray trout
Brevoortia tyrannus	menhaden
Morone saxatilis	striped bass
MEDIUM SALINITY PLANKTON SYSTEMS	
Chrysaora quinquecirrha	sea nettle
Crassostrea virginica	virginian oyster
Acartia spp.	copepod
Callinectes sapidus	blue crab
Brevoortia tyrannus	menhaden
COASTAL SYSTEMS	
Spisula solidissima	surf clam
Penaeus spp.	shrimp
Squalus acanthias	spiny dogfish
Brevoortia tyrannus	menhaden
Stenotomus chrysops	scup
Paralichthys spp.	southern flounder
Menticirrhus americanus	southern kingfish

4.4 Gulf of Alaska

A lack of information prevents the application of the discretized approach (presented in Chapter 3) to the Gulf of Alaska problem. The important role of physical factors in determining the nature of biological communities is the basis for the habitat approach. Very little specific information concerning the physical characteristics of the Alaskan Gulf coast is available. As a result, the habitat concept is not applied to the Gulf of Alaska.

Most of the information available in the Gulf of Alaska concerns the distributions and life histories of commercially important fish and shellfish species (Table 4-5). Even this information provides only an incomplete description of the total populations in the area; for example, some remote areas have no reports of crabs or fish simply because fishing effort has not yet focused there. Most of the data provided does not differentiate between areas where exploratory fishing has not discovered any large exploitable populations, and areas where no exploratory fishing has been undertaken at all.

Some information about the depth range of demersal species (groundfish, crabs, etc.) can be inferred from catch statistics, but more detailed data does not exist. The distributions of the five species of salmon along the coast are even less well known, except for the approximate times of upstream migration and spawning.

Information about the geographical distribution of shore birds is available, but most of it is in terms of "presence-absence" data for large areas of coast. A few areas, notably the Copper River Delta in the Eastern Gulf, are important feeding and breeding areas. As with fish, little specific life history information is available.

TABLE 4-5 AVAILABLE INFORMATION ON SELECTED SPECIES IN GULF OF ALASKA
(complied from U of A, 1973)

SPECIES OR COMMON NAME	DISTRIBUTION	LARVAL LIFE-STYLE	FECUNDITY	MOR-TALITY	GROWTH RATE	DENSITY	CHEMICAL CUES	SPAWNING AREA	SPAWNING SEASON	SPAWNING BEHAVIOR
Cancer magister (Dungeness Crab)	Inshore water 0-50 Fathoms	First pelagic, then benthic	? (one case: 1.5×10^6 eggs/♀)	?	Several estimates available	? (poor information, on a few commercial areas only)	?	? (Location of commercial importance are known, but no complete survey of Gulf)	?	
Paralithodes camschatica (King Crab)	Approx. 80 Fathoms	First pelagic, then benthic	50,000-400,000 eggs/female	?	Several estimates available	"	?	"	"	Fairly well known
Chionoeletes bairdi (Tanner Crab)	50-150 Fathoms	First pelagic, then benthic	5000-150,000 eggs/female	?	Several estimates available	"	?	"	? (Estimates range from Jan.-Sept.)	? (Partially known)
Pandalus spp. (Shrimp)	30-70 Fathoms	Pelagic	600-3400 eggs/female	?	?	"	None	"	Spring	?
Salmon: (Coho, Chum, Pink, King, Red)	? (All along the coast and offshore Gulf waters)	Anadromous	?	?	? (Incomplete information on a *few* species)	?	*Important* in determining which river in which to breed	? (Run up hundreds of major and minor streams, but no complete survey of Gulf)	July-September	Fairly well known for most Salmon sp.
Demersal Fish: *Platychthys* sp. (Flounder) *Lepidopsetta* spp. (Rock Sole) *Gadus* spp. (Cod) *Raja* spp. (Skate) *Atheresthes* sp.	0-50 Fathoms (All along the coast and offshore waters)	Pelagic	?	?	?	?	?	?	?	?
Birds: Trumpeter Swan, Dusky Canada Goose	? (Coastal marshes in general)	Not applicable.	? Low	?	?	?	?	? (Coastal marshes-not known more specifically)		?

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4.5 References

TRIGOM (1973) Preliminary Report on General Habitats from Sandy Hook, New Jersey to Bay of Fundy, Nova Scotia; Part I (August 15, 1973), Part II (October 1, 1973), report prepared by the Research Institute of the Gulf of Maine for CEQ and MIT under contract 08550-CT-38 for Marine Minerals Division, Bureau of Land Management.

VIMS (1973) Environmental Inventory of the Coastal Zone, Sandy Hook to Cape Canaveral: A Preliminary Report, August, 1973 (augmented by Dr. M.H. Roberts, pers. comm., October 19, 1973) prepared by Virginia Institute of Marine Science for CEO and MIT under contract for Marine Minerals Division, Bureau of Land Management.

U of A (1973) Excerpts of Pertinent Biological Information, Gulf of Alaska, Alaska provided for CEQ by Arctic Environmental Information and Data Center, University of Alaska, August 27, 1973.

CHAPTER 5

COMPOSITION AND CHARACTERISTICS OF OIL

5.1 Introduction

Crude petroleum is a complex mixture of hundreds of chemical compounds derived from biological matter which has accumulated in reservoirs in the earth and been subject to physical and chemical processes extending over millions of years. Petroleum from different geographical areas generally contains the same compounds but with different percentage composition. Because the biological effects of groups of similar compounds vary significantly, it is essential to consider the relative abundance of the various compounds in a particular crude oil or in a petroleum fraction which enters the environment.

Petroleum derived substances are ubiquitous in the marine environment. Natural seeps are primary sources in some areas but in modern industrial times significant quantities of oil introduced to marine environments can be attributed to man's activities. When oil is released into the ocean, accidentally or intentionally, physical forces transport it throughout a region. Wind is a prime mover as well as currents, waves and tides. Oil is either dispersed in the water column to unmeasurably low concentration, forms tar balls which appear on the surface, becomes incorporated into sediments, or attaches to various substrates: rocks, mud, sand, plants, animals, and so on. Degradation processes such as evaporation and oxidation continually alter the composition of oil by removal and transformation of various constituent compounds.

5.2 Composition of Oil

Petroleum refers to a broad class of compounds composed of hydrocarbons (greater than 75% of the total constituents) and non-hydrocarbons, i.e., organics containing sulfur, nitrogen, oxygen, and possibly trace metals (Constantinides and Arich, 1967; Bestougeff, 1967).

Composition of crude petroleum is most easily described in terms of hydrocarbon constituents (Bestougeff, 1967). Useful categories of hydrocarbons are:

(1) n-paraffins (normal and branched);
(2) Cyclo paraffins;
(3) Aromatics; and
(4) Naphtheno-aromatics.

Paraffins can make up to 25% of the composition of a crude petroleum. They tend to predominate in the low boiling (40°—230°C) portions of crude oil. They usually have a large number of different configurations due to different positions of the branch. Cyclo paraffins may constitute from 30 to 60% of the composition of petroleum. Although the relative abundance of cyclo paraffins does not change with boiling point the type of compounds may differ from crude to crude. The principal change is the number of rings. Single cyclo-naphthenes form a major part of the cyclo paraffins although two to six rings are not unusual, and even ten rings can be found in lubricating oils. Aromatic compounds contain one or more rings but have quite different properties than cyclohexane or other naphthenes. Benzene and benzene derivatives are major constituents of crude oil. Alkyl-benzenes with one or more substituents are the major low boiling constituents. In the higher boiling fractions tri- and polycyclic compounds are present. Polycyclic aromatic hydrocarbons are found in rather small quantities in petroleum (a few fractions of a percent). Naphthenic hydrocarbons and naphtheno-aromatics form a major component of higher boiling petroleum fractions. Most are substituted with the substituted benzene portion having short chains (methyl or ethyl) and the cycloparaffin part longer alkyl chains. Residual fractions consist of high boiling hydrocarbons of all types, containing oxygen, sulfur, nitrogen and trace metals with molecular weights in the range of 900-3000. They can represent a significant portion of the crude, form 0 to 20%. Though their composition is not completely known they are essentially layers of condensed aromatic and naphthenic rings containing heterocyclic atoms connected by short n-paraffin chains.

In addition to classification by molecular structure, hydrocarbon molecules can be assorted by boiling point ranges. Moore, et al. (1973) have distinguished eight fractions of oil, which are summarized in Table 5.2-1. The fractions identified in Table 5.2-1 correspond closely to the API product classification (Rossini, 1960). Also shown in Table 5.2-1 are estimates of ranges of physical/chemical constants for each fraction.

5.3 Degradation and Weathering Processes

The chemical composition of petroleum in the environment is altered by weathering processes, including evaporation, dissolution, microbial oxidation, chemical-oxidation, and photochemical reactions (Blumer and Sass, 1972). In addition, the rates of degradation are functions of the physical environment: temperature influences most degradation processes; nutrient and inorganic substances effect microbial degradation; the strong forces of the wind, tides, currents and waves have pronounced effects on evaporation, dissolution and sedimentation processes.

Evaporation depletes the lower boiling components (fractions 1, 3 and 5, Table 5.2-1) but leads to little or no fractionation between hydrocarbons

TABLE 5.2-1

BASIC DATA FOR OIL COMPOSITION MODEL

(from Moore et al., 1973)

Fraction	Description[a]	% by wt.[a] in Crude Oil	Density[b] (gm/ml)	Boiling Point[b] (°C)	Molecular Weight[b]	Vapor Press.[b] @ 20°C (mm)	Solubility[c] ($gm/10^6 gm$ Distilled H_2O)
1	Paraffin C_6-C_{12}	.1-20	.66-.77	69-230	86-170	110-.1	9.5-.01
2	Paraffin C_{13}-C_{25}	0^+-10	.77-.78	230-405	184-352	.1	.01-.004
3	Cycloparaffin C_6-C_{12}	5-30	.75-.9	70-230	84-164	100-1.	55-1.
4	Cycloparaffin C_{13}-C_{23}	5-30	.9-1.	230-405	156-318	1.-0	1.-0
5	Aromatic (Mono- and di-Cyclic) C_6-C_{11}	0-5	.88-1.1	80-240	78-143	72-.1	1780.-0.
6	Aromatic (Poly-Cyclic) C_{12}-C_{18}	0^+-5	1.1-1.2	240-400	128-234	.1-0	12.5-0
7	Naphtheno-Aromatic C_9-C_{25}	5-30	.97-1.2	180-400	116-300	1.-0	1.-0
8	Residual (including heter-ocycles)	10-70	1.-1.1	>400	300-900	0	0

(footnotes on following page)

TABLE 5.2-1 (Continued)

a - for further detail see:

1. Bestougeff, M.A. in Nagy, Bartholomew and Colombo, Fundamental Aspects of Petroleum Geochemistry, Elsevier Publishing Company, New York, New York, 1967.

2. Rossini, Fredrick D., Hydrocarbons in Petroleum, Journal of Chemical Education, Vol. 37, No. 11, November 1960.

3. Smith, H.M. Qualitative and Quantitative Aspects of Crude Oil Composition, U.S. Bureau of Mines Bulletin 642, 1968.

b - taken or estimated from:

1. Handbook of Physics and Chemistry

2. Physical/Chemical Constants for Organic Compounds

c - taken or estimated from:

1. Klevens, H.B., Solubilization of Polycyclic Hydrocarbons, Journal of Petroleum Chem., 54:283-298 (1950)

2. Peake, Eric, and G.W. Hodgson, Alkanes in Aqueous Systems. II. The Accommodation of C12-C13 n-Alkanes in Distilled Water, J. Am. Oil Chemists' Society, Vol. 44, pp. 696-702, Dec. 1967.

3. McAuliffe, Clayton, Determination of Dissolved Hydrocarbons in Subsurface Brines, Chem. Geol., 4(1969), 225-233.

4. Gerarde, H.W., Toxicology & Biochemistry of Aromatic Hydrocarbons, Elsevier Publishing, London, 1960.

of the same boiling point that belong to different structural series (Blumer, 1970).

Dissolution also removes preferentially the lower molecular weight components of an oil. However, aromatic hydrocarbons have a higher solubility than n-paraffins of the same boiling point (Blumer, 1970).

Biochemical (microbial) attack affects compounds within a much wider boiling range than evaporation and dissolution. Hydrocarbons within the same homologous series are attacked roughly at the same rates. Normal paraffins are most readily degraded. In gas chromatograms this type of degradation manifests itself as a lowering of the ratios between straight chain and adjacent branched paraffins. Extended biochemical degradation then results in gradual removal of the branched alkanes. Cycloalkanes and aromatic hydrocarbons (fractions 3-8) are more resistant and disappear at a much slower rate (Blumer, 1970).

Chemical and photo-oxidation also effect petroleum substance but the processes are not well understood. That photo-oxidation can be significant has been recently demonstrated by Freegarde, et al. (1970).

The rates of degradation of each fraction are not well known. In general, the effects of weathering processes are the rapid (1-2 days) depletion of lower boiling fraction (boiling point < 250°C) from a slick by evaporation and dissolution and slow degradation (in terms of years) of higher boiling fraction by microbial and chemical oxidation (Moore, et al. 1973).

The heavy residuals of oil which are not degraded or deposited in sediments are found in floating tarry globules known as tar lumps or tar balls. These are ubiquitous and copious (Morris and Butler, 1973). In this form, petroleum can be transported long distances to be deposited later in bottom sediments or washed ashore.

Oil can be classified as weathered or unweathered. By weathered oil is meant that concentration in a slick of hydrocarbon fractions with boiling points less than 250-300°C has been reduced to concentrations which do not cause toxic effects (See Chapter 6). One to two days has been estimated as a typical time oil must be in the pelagic environment to be considered weathered.

An important process affecting the ultimate fate of oil in marine environments is sedimentation and deposition in subtidal and intertidal substrates. Although chemical composition of oil is not altered directly, oil incorporated in unconsolidated sediments may persist for long periods of time (see Section 5.4), especially higher boiling fractions. However, loss of low boiling fractions from unweathered oil incorporated in sediments may also proceed at much slower rates than from a slick (months rather than hours or days). This hypothesis is suggested by data from the West Falmouth spill (Blumer and Sass, 1972).

5.3.1 Effect of Physical Variables

It is clear from the foregoing discussion that rates of weathering may be significantly affected by physical variables such as temperature, light, water turbulence, oxygen and microbial nutrient concentration, and substrate particle size.

In theory, the relevant physical parameters described can be functionally related to the various degradation processes (microbial, chemical, evaporation, etc.) and the residence time of oil computed for a particular habitat. Unfortunately, the problem is additionally complicated by the complex chemical nature of oil, as has been discussed. A model then must account for the effect of each physical factor on each of the weathering processes for each of several fractions of hydrocarbons. It has not been possible to develop such a model during this study. However, it is doubtful that appropriate data exists to derive rates of degradation. In addition, many of the functional relationships are poorly known. For example, the relationship between sediment particles and adsorption/absorption of oil is extremely important, but little understood (Meyers, 1972). Although quantitative measures of degradation rates have not been identified and a complete listing of interrelationships among physical factors and weathering is not possible at this time, illustrative cases can be described. Substrate nutrients affect microbial degradation. Nitrogen and phosphorus have a strong positive effect on the degradation rates--in so far as they are limiting to microbial growth. Temperature influences virtually all of the processes. Evaporation is certainly increased by higher temperature, as is dissolution. Rates of oxidation processes proceed faster at higher temperatures. Microbial degradation is typically enhanced by increased temperature up to the temperature tolerance limit of the organisms involved. Oxygen must be plentiful for aerobic microbial degradation to be active. Indeed, this may be a limiting factor in many locations and might explain the long residence times in sediments, like muds, where anerobic conditions are known to exist (Gunkel, 1973). Also, sediment particle size can cause incorporation and absorption of oil, thus storing the oil, resulting in a longer persistence time. In addition, finer sediments have a greater storage capacity than coarse sediments. Finally, exposure of oil to light of higher intensity and/or longer duration increases photo-oxidation and decreases persistence time.

Based on the foregoing discussion, it is hypothesized that oil deposited in sediments will in general persist longer in northern OCS regions than in southern OCS regions. However, the magnitude of this difference is not estimated.

5.4 Observed Persistence of Oil in Marine Subsystems

Although a model describing weathering and degradation of oil in marine environments is not developed, reports of observations following actual spill events do provide an empirical basis for estimating persistence times. The necessary data for a spill are amount and composition of oil deposited in a habitat and observations on the length of time oil remains in the habitat. Data of this type are best obtained by analytical techniques, such as chromatography, but few spill investigators have employed such techniques. More often, visual observations are made and presence or absence of petroleum substances is only grossly determined. In spite of resulting problems of interpreting reported data, some insight is gained by reviewing post-spill studies which have given attention to persistence of oil. Spill events reviewed are:

1) San Francisco Bay, California - Arizona Standard and Oregon Standard
2) Chedabucto Bay, N.S. Canada - Arrow
3) West Falmouth, Massachusetts - Florida
4) Wreck Cove, Washington - General M.C. Meigs
5) Santa Barbara, California - Channel Well A-21
6) S.W. England - Torrey Canyon
7) Casco Bay, Maine - Northern Gulf

The following are summaries of data from reports on these spills, which emphasize data illustrating the presence of oil and its persistence in a habitat.

1) <u>San Francisco, California</u>. The spill occurred on January 18, 1971 when an estimated 20,000 bbls. of Bunker C was released. Oil entered two types of habitats: rocky shores and mussel reef. The oil was unweathered, entering the habitats several hours after the accident. The quantity, type, or composition of the oil is not specified. A survey in August, 1971 showed mussels still coated with oil (Chan, 1973). This, the only physical observation made, infers that oil was in the mussel reef zone for at least six months. The report estimates that two years after the spill all "signs" of oil will have disappeared from the rocky shores (Chan, 1973); these "signs" are probably visual. Thus a minimum estimate of persistence of oil on the rocky shore of San Francisco Bay is two years.

2) <u>Chedabucto Bay, N.S., Canada</u>. On February 4, 1970 a spill released approximately 108,000 bbls. of No. 6 (Bunker C) fuel oil into the Bay. The oil entered two habitats: sandy beach and rocky shore. Ultraviolet spectrophotometry showed 300 ug Bunker C/g wet weight of sediment in the first three meters on Jerseyman Island in April, 1972 (Scarratt and Zitko, 1972). This was comparable to the initial quantities found. Hence 26 months after the spill the mud bank had shown little loss of oil. At the same time only 11 and 5 ug of Bunker C/g wet weight of gravel was found off of Crichton Island (Scarratt and Zitko, 1972). This was only marginally greater than controls so oil did not persist in the gravel. Re-oiling, due to the original spill, occurred in Chedabucto Bay as late as the summer of 1973. The lagoons (salt marshes, estuaries) show 50% of the original oil content, but not the rocky shores (Thomas, 1973). From this data, persistence of oil in the salt marsh and muds can be estimated as at least three years.

3) West Falmouth, Massachusetts. On September 16, 1969 an estimated 4,500 bbls. of #2 fuel oil was released. Two years after the spill 117 mg fuel oil/100g dry weight of sediment was found in Silver Beach Harbor (station 31). This was the heaviest hit area and it would be expected to have the greatest concentration of oil. The normal alkanes show an initial rapid degradation but after two years they were still reported as present (Blumer and Sass, 1972). From gas chromatography (utilized throughout the study) it was demonstrated that 30% of the oil in the sediments in April 1971 was aromatic. The oil penetrated three inches into the sediments at Station 31; and, oil was found in the marshes at least five feet below the surface (Blumer and Sass, 1972). The authors estimate that for at least two more years, oil will be found in the sediments (Blumer and Sass, 1972) , that is a total estimate of four years since oil first entered the sediments. The $n\text{-}C_{17}/P$ ratio was nearly constant for eight months in areas where heavy oiling took place, suggesting a delay in bacterial degradation (Blumer and Sass, 1972). In the marsh undegraded fuel oil was still present four years after the spill (Teal, 1973). Because Buzzards Bay has moderate total organic content the authors conclude a poor retentive capacity for hydrocarbons (Blumer and Sass, 1972). The straight chain hydrocarbons are utilized by bacteria, without delay, in surface of the salt marshes (Blumer and Sass, 1972). There is evidence that between 2.5 and 7.5 centimeters into sediments at Station 31 the oil was less degraded than at the surface; after two years oil below the surface of the sediments was degraded to the same extent as the surface sediment oil after 10 months (Blumer and Sass, 1972). In the Wild Harbor River (Stations II, IV, and V) the fuel oil was not as persistent; two years after the spill there was an average of 20 mg oil/100g dry weight of sediment, although for the month

of April of 1970 the average was 60mg oil/100g dry weight, indicating a re-oiling (Blumer and Sass, 1972).

The persistence time estimate of four years, as stated in the report, has recently been revised to over five years (Dr. J. Teal, pers. comm.).

4) Wreck Cove, Washington. On January 6, 1972 approximately 3,000 bbls. of Navy Special fuel oil was released. Storm conditions broke the oil into globules, which arrived on the beach in 5 to 30 centimeter diameter sizes. The sole observation made was that in the upper tidal pools of the rocky ledge the oil was trapped for several months (Clark and Finley, 1973).

5) Santa Barbara, California. Commencing on January 28, 1969 and lasting several weeks a blowout released an estimated total of 33,000 bbls. of oil. Samples taken in the sediments on March 31, May 1, and June 13, 1970, showed no evidence of a reduction in oil content over this period (Straughan, Vol. 1, 1971). Oilwas found present in sediments as late as June 1970 (Straughan, Vol. 2, 1971). Straughan comments that the effect of oil spilled on the rocky intertidal stations appears less important than other environmental factors (i.e., sand and substrate) (Straughan, 1973). The author also believes that the sandy beaches recovered from oil contamination due to the spill during the interval 1972-73, because chromatographic analysis indicates that the oil found after this period was due to natural seeps. However, weathered oil on the cobbles in the upper intertidal zone, found in February 1973, was possibly linked to the spill (Straughan, 1973). This data is evidence that oil may persist in sandy and rocky shores for at least three years.

6) South West England: The Torrey Canyon. On March 18, 1967 an estimated 860,000 bbls. of Kuwait crude oil was lost at sea. Large amounts of emulsifiers were used in the clean up operation. However, in a few areas

emulsifiers were not directly used and oil was removed by the biological and physical forces.

Brown oil films were observed between tide marks on rocks several months after the oil arrived. The splash zone was found to have blackened oil on it, but after five months this was unobservable (Smith, 1968).

Oil persisted longer on the sandy shore. At Mawgon Porth the following conditions were observed (Smith, 1968):

1. April 22 - 1 to 5% oil; brown layers visible.
2. May 11 - 0.42% oil, grey layers visible.
3. June 11 - general greyness but no layers visible.
4. August 11 - 0.62%; grey layers apparent at 20 to 40 cm depths.

The impression of the investigators was that degradation occurred but at a slow rate (Smith, 1968). Oil was found exposed on the sand beaches as late as the spring of 1970, where it seems seasonal movements of sand had kept it buried (Spooner, 1971).

Hayle estuary on March 28 and 29 received an influx of oil and there was no widespread use of detergents in this area. By mid August a black oil rim was still visible on the vertical walls of the estuary and harbor, but the authors claim it was reduced considerably due to weathering (Smith, 1968).

The data, mostly visual, indicate oil persistence in both the rocky shore and sandy shore of at least several months.

7) Casco Bay, Maine. The spill occurred on November 25, 1963 releasing between 20,000 to 25,000 bbls. of Iranian Agha-Jari crude. Colored photographs, taken in 1970-71, were used to ascertain the presence of oil residue on rocks in Simmond's lobster pound (Shenton, 1973). Samples of both sediments and soft shell clams from July 20, 1972 show evidence of

a high contamination level of oil. Gas chromatograms show hydrocarbons in the sediments of 6,800 ppm.

There were no other accidents in this area since 1963, yet nearly ten years after the spill, oil was found in the sediment (Shenton, 1973). Chromatographic analysis shows this oil to match with the originally spilt oil.

In summary, data from eight different oil spill reports has been collected. Estimates of the observed persistence of oil in the different habitats have been made and are summarized in Figure 5.4-1. Care must be taken in interpreting this figure. Many observations depend more on the length of study than on the actual time oil remains in a habitat. Hence these are minimum residence times of oil. In many cases the investigating reports terminated their data collection before the oil was no longer detectable (either visually or analytically). Thus the wide variation of estimates, e.g. Rocky Shore shows a minimum time of weathered oil from greater than five months to at least three years. This range is chiefly attributable to the length of investigation, not to differences in persistence time of oil. Most importantly this chart provides some "feel" for the duration of petroleum persistence in a habitat.

5.5 Alaska--Some Considerations

Because severe winters produce unusual extremes in the physical parameters of Alaska, this section intends to make explicit some aspects of the degradation of oil in relation to the physical parameters which were briefly described in section 5.3.1. The Gulf of Alaska is, however, a milder region and not ice-chocked as other waters of the northern Alaska coast.

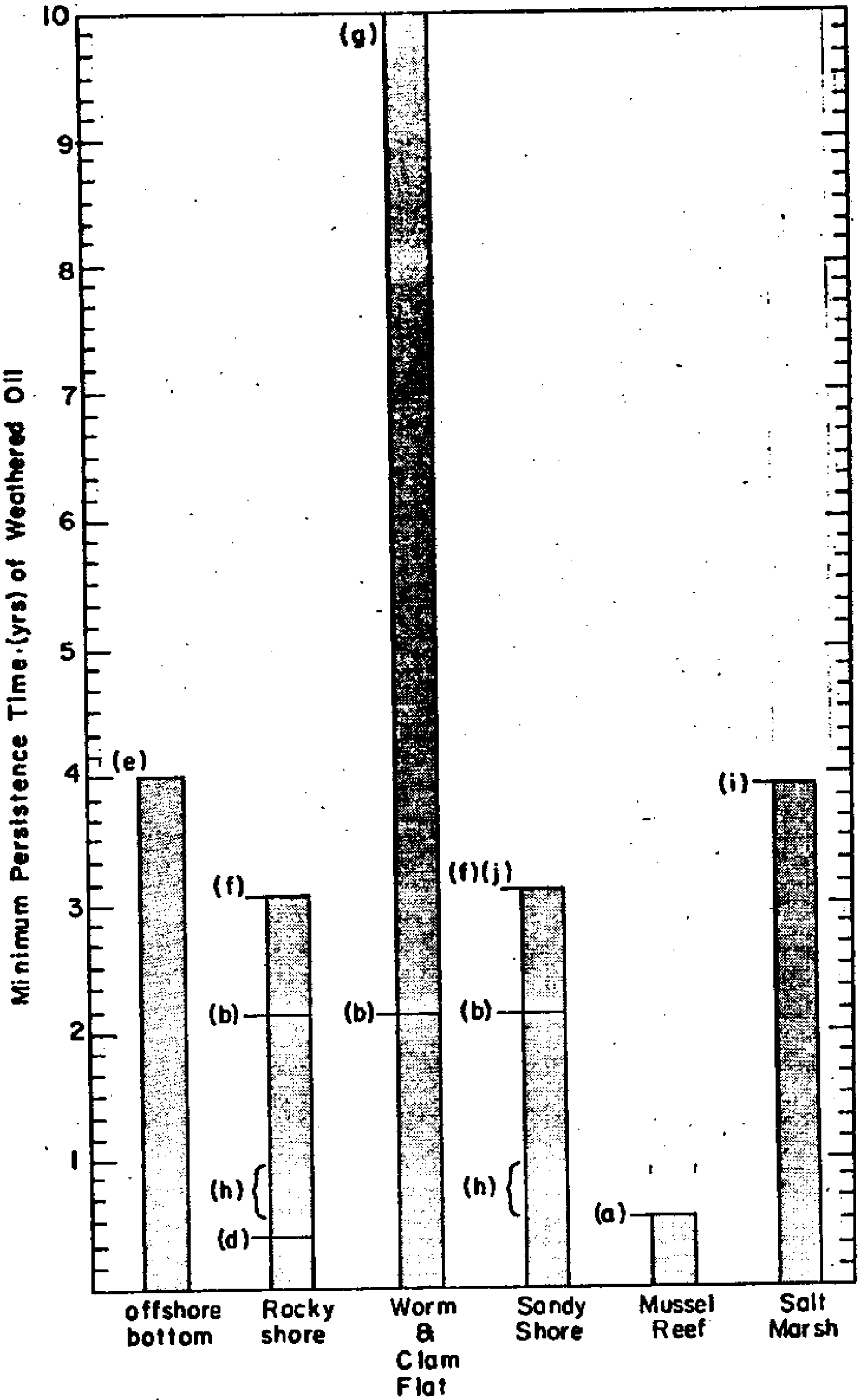

Figure 5.4-1. Observed persistence of petroleum substances in various marine habitats following actual oil spills. Maximum times shown do not necessarily imply complete removal of oil, but may represent author's estimate of persistence or termination of study. See explanatory notes on next page.

Figure 5.4-1 (continued)

(a) *Mytilus californianus* were described as having an oil coating after six months; non-lethal effect (Chan, 1973).

(b) Analytical determination of oil (Scarratt and Zitko, 1972).

(c) Author is referring to lagoon, which can be broadly interpreted as a salt marsh (Thomas, 1973).

(d) The authors cite visual evidence of oil retained in rocky ledge by false eel grass for several months (Clark and Finley, 1973).

(e) Author's estimate after two years; analytical methods; used #2 fuel (Blumer and Sass, 1973).

(f) Interpretation from statement made by authors; analytical techniques: crude oil (Straughan, 1973).

(g) Visual observation and analytical. JP-5 and #2 fuel (Shenton, 1973).

(h) Visual observation--emulsifiers used on crude (Smith, 1968).

(i) Teal, 1973.

(j) Gas-liquid chromatography analysis (Spooner, 1971).

Temperatures in northern Alaskan waters and coastlines are lower than on the Atlantic coast, but those in the Gulf are comparable. The low temperatures of winter would greatly impede microbial degradation of oil on the shore, despite the presence of psychrophillic bacteria. The microbes of Cook Inlet are reported as being largely non-psychrophillic (Button, 1971). However, weathering does occur as observed by an increase in oil density approaching or exceeding the density of sea ice in six to fifteen days during the winter months (McMinn, 1972). Some results would indicate a loss of C_{12} or lower in about eight hours (season not specified) (Kinney, et al., 1969). Moreover, "warm" oil accidentally introduced into ice- and snow-covered marine habitats would result in a sandwich effect of oil between the two layers. Oil in this state may remain relatively undegraded, perhaps until the spring thaw. This oil will not be readily absorbed by the ice and snow mixture (McMinn, 1972). Evaporation would be reduced and the toxic low-boiling aromatics would remain.

In the winter the amount of daylight is significantly reduced, affecting photo-chemical oxidation. Clearly oil in bottom sediments, containing toxic components, would remain longer during the colder months.

The highly turbulent areas of Cook Inlet can cause rapid dispersal of the oil into small particles, to millimeter size within three or four days (Button, 1971). This would probably enhance slightly the degradation of oil.

In summary, weathering of oil in the Alaskan coast will not be faster than in the north Atlantic, and most likely will be much slower.

5.6 Summary and Conclusions

The length of time oil discharged in the marine environment persists as distinguishable petroleum substances is strongly influenced by physical characteristics of the environments exposed to oil. Unfortunately, an exact formula (model) for estimating residence times of oil in different habitats does not exist nor can reliable estimates be made of residence time from empirical data obtained from actual spill sites. Nevertheless, several observations of available spill data are of limited use.

First, habitats composed of non-consolidated sediments demonstrate persistence of oil for at least four or five years. In addition, evidence in one case suggests a residence time as long as ten years (Worm and Clam Flat). An expected minimum residence time of oil in unconsolidated sediments is between the ranges of four to ten years. Local conditions may change such estimates several fold.

Second, hard substrate habitats, i.e., rocky shores, are characterized by minimum residence time of two or three years except the case of the mussel reef where the investigation terminated before the oil was removed).

Finally, one can expect a variation of the rates of degradation among habitats in different coastal regions. Evidence is scarce and only an intuitive argument can be made for the relative differences among regions. One plausible ordering of regions from highest degradation rates to lowest is: Southern Atlantic, Northern Atlantic, and Gulf of Alaska. However, this is only a hypothesis. Moreover, the degree of variation is even less well defined.

In summary, oil discharged in the marine environment can be expected to remain for several years minimum, particularly in the loose sediments. Regional differences do exist but a recipe for determining these differences is not at hand. Local conditions can also effect residence times of oil and must be taken into account. However, the fact that the oceans are not a sea of petroleum hydrocarbons indicates that ultimate mineralization to CO_2 takes place.

5.7 References

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CHAPTER 6

RESPONSE AND SENSITIVITY OF INDIVIDUAL ORGANISMS TO OIL

An assessment of ecological impacts of oil depends on effects of oil at all levels of biological organization--subcellular, cellular, organism, population and community. This chapter considers collectively subcellular, cellular and organism effects of oil as effects on individuals. Population and community effects--the effects of ultimate interest--of an oil spill result from the aggregate responses of individuals interacting in the environment. If the sensitivity to oil of individuals is known and the population and community dynamics of the system are understood, then effects of hypothetical spills of oil can be deduced. For a particular spill, estimates can be made of concentrations of various hydrocarbons to which organisms are exposed. If exposures are within a range to which individuals of various species are sensitive relative to the effects described in section 6.1, an initial impact can be estimated. Ensuing population/community changes (recovery) can then be estimated, assuming necessary data are available.

For the most part effects on individuals are exemplified in laboratory and field toxicity tests. Experiments are designed which attempt to identify parameters such as the concentration of oil, or some constituent thereof, which is lethal to 50% of the test organisms within a specified time period (typically called LC_{50} data). Several authors have recently reported extensive literature reviews summarizing the state-of-knowledge regarding effects of oil on individuals (see for example, NAS, 1973 ; Moore, et al., 1973; Boesch, et al., 1974; Nelson-Smith, 1973; Clark, 1971). Additional extensive literature review has not been undertaken in this study. Results are described following the format previously reported by Moore, et al. (1973). The reader is referred to the reviews cited above for additional documentation of the effects of oil on individuals.

6.1 Types of Effects

Exposure of an organism to oil and the resulting response actually involves many complex cellular processes which cause certain physiological and behavioral changes exhibited by the individual. Rather than attempt to detail these complex phenomena, the overall effects of oil on individuals are lumped into five categories: 1) direct lethal toxicity; 2) sub-lethal disruption of physiological or behavioral activities; 3) the effects of direct coating by oil; 4) incorporation of hydrocarbons in organisms which cause tainting and/or accumulation of hydrocarbons in food chains; and 5) changes in biological habitats (from Moore, et al., 1973).

Lethal toxicity refers to the direct interference by hydrocarbons with cellular and subcellular processes, especially membrane activities, leading to organism death. Sub-lethal disruption also refers to interference with cellular and physiological processes but does not include effects causing immediate death. The most important effects in this category are disruption of behavior, especially feeding and reproduction. Although toxic effects involve cellular level changes, histological analyses are rarely included in toxicity studies. The effects of direct coating do not result from biochemical interference of oil with cellular activities. The primary effects are smothering or mechanical interference with activities such as movement and feeding. The incorporation of hydrocarbons in organisms is of interest for two reasons: 1) because of potential accumulation of polycyclic aromatic hydrocarbons (PAH), especially carcinogens, in various marine organisms; and 2) tainting of edible organisms with hydrocarbons. Habitat changes consist of changes in the physical or chemical environment, which result in significant shifts in species composition and geographic distribution in the region of concern.

An additional "effect" of oil which can be hypothesized, but is virtually unstudied, is adaptive changes that may occur in the short-term (less than one generation)--acclimation--or in the long-term (many generations)-- genetic changes. Adaptive effects alter responses to the five effects listed previously. If acclimation occurs, the sensitivity of an individual to effects of oil may decrease noticeably under prolonged or repeated exposure, thereby increasing the individual's resistance to oil. However, the poorly understood complex process of acclimation may involve accompanying changes which further effect the individual's overall probability of survival in an unknown manner.

Genetic adaptation is actually a population level phenomena. Natural selection operates to select those individual progeny in each generation which are best able to cope with the environment as it exists. Persistent petroleum-derived hydrocarbons in the environment may result over many generations in a population of more tolerant individuals. Again, however, this poorly understood process may be accompanied by other changes, unrelated to hydrocarbon tolerance--changes which may be desirable or undesirable.

Both of these adaptive effects are essential characteristics of living systems. However, the processes are poorly understood in general, and virtually unknown relative to their implication for responses to and effects of oil. However, it is clear they may play important roles in determining the ultimate effect of oil in marine environments.

6.2 Data Base Evaluation (taken from Moore et al., 1973)

Before discussing the documented responses of organisms to oil, it is necessary to review the experimental procedures which provide the data base. Although a substantial number of studies have been carried out, investigating various biological aspects of oil pollution, there have been no comprehensive systematic studies of the whole problem as yet. In addition, there is a lack of standardization of the results of various studies. Accurate measurements have not been made of the concentration and composition of crude petroleum in solution, and the concentration and composition of fractions of petroleum in the bodies of animals and plants tested. Thus, in most cases, important pieces of information that provide the basis for comparison of different studies are missing. The complexity of petroleum substances amplifies this problem and makes it difficult to accurately analyze and specifically attribute biologically observed effects to even a limited fraction of the crude petroleum. Finally, a number of physical and biological processes significantly change the composition of crude petroleum over time, adding further difficulties. Despite these problems, there is enough information available to intelligently discuss various effects, the specific sensitivities of representative biological organisms, and draw some conclusions about the overall effects of crude petroleum and petroleum products.

Laboratory experiments are designed to examine the biological consequences of the controlled exposure of plants and animals to specific concentrations of pollutants. These experiments normally consist of a number of animals or plants of a particular species (e.g. fish, shellfish, algae) being placed in a large tank in which they are exposed to water or sea water containing petroleum components. The organisms are allowed to remain in the tank for varying periods of time (from minutes to hours), and then removed and, if still alive, they may be placed in non-polluted water for varying periods.

Most studies evaluate the so-called acute toxicity which is reported as the dose required to kill a specified percentage (usually 50%) of the test organisms during the exposure period. Various notations are used, such as XLC_y, XLD_y or XTM_y, where X denotes the exposure period in hours and y denotes the percentage killed (XLD_y is used in this report). For example, $8LD_{50}$ would be the dose required to kill 50% of the test organisms in 8 hours. In a few experiments, the organisms that survive the acute effects are observed for longer periods of time (days to weeks) and long-term toxicity and sub-lethal effects evaluated. Todd et al. (1972) and Whittle and Blumer (1970) have reported the only extensive experiments which deal explicitly with the influence of sub-lethal concentration on behavior, survival, reproduction and community structure.

There are several severe limitations to the usefulness of experiments such as those described above. Most importantly, no standard experimental methods have been developed, especially with respect to petroleum fractions and media monitoring. The variability of composition, limited solubility and weathering petroleum products require that the soluble fractions in the media be measured during the toxicity tests. However, this is almost never done. As a result, comparison of data is extremely difficult because different petroleum substances and different methods of addition (surface film, emulsion, etc.) are utilized in different experiments. Furthermore, the organisms are subjected to unnatural conditions and deprived of important interactions with other species and other normal environmental conditions.

Concentrations of hydrocarbons in the tissues of test organisms, before and after the exposure to oil, are rarely determined. The gas chromatography and spectroscopy equipment used in analyzing hydrocarbons is expensive and relatively complex, thus inhibiting widespread application to oil toxicity studies. Because these analytical techniques have not been extensively used as yet, little data are available relating to background concentrations of hydrocarbons in the environment and in the tissues of individual species.

Even if hydrocarbon concentrations in animal tissues are measured after exposure, they are often reported in a form which makes comparisons with other studies difficult. Hydrocarbon concentrations are reported in the literature as grams per kilogram of dry weight tissue, or grams per kilogram of wet weight tissue, thus leaving to the reader the task of determining what percentage of the test organism is water. Frequently, the petroleum additive is described in the literature merely as "oil", "light crude oil". "mineral oil", etc., omitting the important information about composition especially soluble fractions.

Due to these shortcomings, the primary value of laboratory experiments is to establish order of magnitude boundary conditions on lethal toxicity. That is, concentrations of various substances can be identified which, if significantly exceeded, have a high probability of killing the organism of interest.

Only a limited number of experiments on plants and animals in the field have been undertaken. They consist of spraying or pouring crude oil, weathered crude oil, or petroleum products on specific areas in salt marshes or various coastal areas. Changes in fauna or flora are noted for various periods after their exposures. Spraying may be repeated at different time intervals over a period of months or years. The results are normally described as quantitative changes of numbers and density (number of organisms per unit area) of animals or plants present. In general, field experiments have the advantage of taking place in a "natural" habitat, thus allowing complex effects related to survival in an ecosystem to be evaluated. However, they are less quantitative and controlled. Frequently, the concentration of oil applied per unit area is not known precisely. In addition, although the experiments take place in a natural setting, they may be so restricted in size that significant effects are not observed. A number of variables, such as predators, weather conditions, and physiochemical changes, cannot be controlled, and frequently are not noted in the literature. Major salinity changes because of runoff from heavy rains occurred in the Santa Barbara Channel at the same time as the oil spill. It is difficult to distinguish between deaths attributed to "natural" changes and those due to oil.

Rather extensive data are available from studies following actual accidental spills. Unfortunately prior examinations of the flora and fauna affected is usually not available. Typically these studies describe the organisms remaining after the spill, but do not include estimates of the concentration of hydrocarbons to which the organisms were exposed. Often, dead organisms are counted, although only rarely are hydrocarbon concentrations in their tissues measured. The actual impact of a spill is highly dependent on weather conditions, time of year, local hydrography and physiography, and the area's previous history of oil spills. The length of time between release of the oil and its coming ashore is rarely directly stated in the literature. However, the extent of weathering that the slick has undergone can usually be ascertained by closely examining the description of the accident causing the spill which usually precedes discussion of biological effects in the article.

6.3 Sensitivity of Individual Organisms--A Review (adapted from Moore et al., 1973)

Assessments of the various effects of oil on individual organisms is summarized in the paragraphs below. For each of the five classifications of effects (see Section 6.1) data reported in the literature is summarized for several organism categories including: flora (phytoplankton, kelp, marsh grasses, etc.), pelagic fauna (finfish, crustaceans, larvae, etc), and benthic fauna (mollusks, crustaceans, etc.).

6.3.1 Lethal Toxicity

The data summaries for toxic responses (Tables 6.3-1 through 6.3-8, from Moore et al., 1973) follow a standard format. For each organism or group of similar organisms the tables specify the common and scientific names, the type of experiment (laboratory, field or actual spill incident), the substance and amount used or spilled, an estimate of the actual amount of aromatic derivatives in solution, the test duration, the reported response, a reference citation and general remarks. Because toxic responses result almost exclusively from the soluble fractions of oil, it is important to determine the concentration of soluble hydrocarbons. In almost all reported cases this information is not provided. The estimates compare a variety of petroleum substances, and from the description of experimental methods given by the original authors. Soluble paraffin fractions are not included, because only the very low boiling fractions (less than C_{10}) are toxic and even these only in nearly saturated solutions (Goldacre, 1968; Nelson-Smith, 1970) which would not be obtained under test or field conditions with petroleum mixtures.

6.3.1.1 Flora

Table 6.3-1 summarizes the toxic response of marine flora to hydrocarbons. Phytoplankton sensitivities vary over a wide range. A few species are apparently sensitive to concentrations of soluble aromatic derivatives (SAD) as low as 1 ppm. However, most species are unharmed by concentrations of 100 ppm or higher. Kelp are affected similarly. Note that Wilber (1968) reports no effects on kelp by the paraffin hexane (10 ppm), but significant effects of the aromatics benzene and toluene (10 ppm). Kelp and similar macrophytes can be expected to be reasonably resistant due to excretion of mucous substances which coat the stems and fronds of the plant, preventing damage. Most data for the response of marsh grasses deal with effects of coating. However, it is reasonable to assume a toxic response to SAD concentrations of 10-100 ppm. Baker (in Cowell, 1971) provides a summary of the effects of oils on plant physiology. The long-term impact of spilled oils on plants depends on both toxic and coating effects, frequency of coating, and on the time of year.

6.3.1.2 Pelagic Fauna

For the purposes of discussing oil effects on individuals, pelagic fauna are divided into finfish, larvae of all marine organisms (except those few with benthic larvae) and pelagic crustaceans. Data on finfish toxicity (Table 6.3-2) are not extensive and onlv a few species indigenous to the Gulf of Maine have been used in experiments. The data are not very conclusive, but an estimate of a toxic threshold of 5-50 ppm SAD seems reasonable, especially in light of the data reported by Wilber (1968). Because finfish are hypothesized to avoid contaminated areas (Nelson-Smith, 1973), there has not been a strong interest in the toxic response of these organisms.

The toxic effects of oil on larval stages of many marine organisms have been much more extensively studied (Table 6.3-3). Several investigators report that larvae appear to be 10-100 times more sensitive than adults (Mironov, 1968; Kuhnhold, 1970; Corner, et al., 1968). Typical concentration of SAD causing lethal toxicity are .1-1 ppm. However, at the lower concentrations death may be a delayed response. Typically the larvae may develop abnormally, leading to death several weeks after exposure. In a non-laboratory environment, such maldeveloped individuals are much more susceptible to predation, competition and other secondary effects. It is also interesting to note that larvae tend to be more sensitive than eggs. Apparently, this is due to the protection afforded the embryo by the chorion.

Table 6.3-4 summarizes the sparse data reported on the toxicity of pelagic crustaceans (shrimp and copepods). The critical concentrations may be somewhat lower than those for fish and 1-10 ppm SAD is probably the lower threshold. Smith (1968) suggests that because of the small size (a few millimeters) of many pelagic crustaceans, toxicity may be a function of size. That is, the larger individuals are possibly more resistant.

6.3.1.3 Benthic Fauna

The benthic fauna are divided into four categories: gastropods (snails, limpets, etc.), bivalves (clams, etc.), crustaceans (shrimp, lobsters, etc.) and all others (worms, anemones, etc.). Apparently gastropods are the most resistant and crustaceans are the most sensitive.

Most gastropods studied (Table 6.3-5) indicate a rather high resistance to hydrocarbon toxicity and periwinkles (*Littorina littorea*), a common intertidal snail, are apparently very resistant. The critical concentration may be 100-200 ppm or more. Limpets (*Patella vulgata*) demonstrate the only significant deviation and appear to have a critical threshold concentration of less than 5 ppm. The relatively high resistance of most gastropods may be due to secretion of a mucous substance (Shelton, 1971).

Bivalves, including oysters, clams, cockles and mussels are moderately resistant to oil (Table 6.3-6). The ability to close their shells and seal off the ambient water mass acts as an effective protection mechanism. However, this closed condition cannot be maintained indefinitely and, in fact, cockles tend to "gape" making them more susceptible (Simpson, 1968). Typical critical concentrations for most bivalves are 5-50 ppm SAD.

Both benthic crustaceans and other miscellaneous benthic organisms (Tables 6.3-7 and 6.3-8) are apparently fairly sensitive to SAD. Threshold concentrations appear to be 1-10 ppm of SAD. Burrowing organisms may also be threatened by alterations in the substrate texture and structure.

6.3.1.4 Summary of Toxicity Data

Moore, et al. (1973) propose an aggregation for toxicity sensitivity by grouping organisms as shown in Table 6.3-9. Although this level of

TABLE 6.3-1 SUMMARY OF TOXIC RESPONSES FOR MARINE FLORA (Cont'd) (from Moore, et al., 1973)

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE AND REPORTED AMOUNT	ESTIMATED HYDRO-CARBONS IN SOLU-TION	DURATION	RESPONSE	REFERENCE	REMARKS
Phyto-plankton	Prasinophyceae Halosphaera sp. Pterosperma sp.	incident: Torrey Canyon	crude slick			lethal toxicity (reduced population)	Smith (1968)	Cysts (reprod cells) of these were disrupted by oil, since they float near surface
"	various species	Laboratory	BP 1002 emulsifier without kerosent	$1.2x10^{-3}$ ppm 1.2 ppm		generation time & lag phase lengthened below 1.2 ppm lethal toxicity at 1.2 ppm	"	brackish water species better able to withstand membrane damage caused by emulfifier (sol'n in lipid layer)
Salt marsh grasses	various species	Field experiment (Milford Haven)	fresh crudes (Kuwait)			see p. 31 of Cowell annuals most susceptible, perennials most resistant	Baker (1971)	germination in annuals inhibited seasonally dependent
Kelp	Macrocystic angustifolia	Laboratory	benzene n-hexane toluene	10 ppm 10 ppm 10 ppm	96 hrs. 96 hrs. 96 hrs.	slight photosynth. inhib. no effect visible injury, 75% reduction in photo-synth.	Wilber (1968)	

TABLE 6.3-J SUMMARY OF TOXIC RESPONSE FOR MARINE FLORA (Cont'd) (from Moore, et al., 1973)

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE AND REPORTED AMOUNT	ESTIMATED HYDROCARBONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
Phyto-Plankton	Numerous Species	Laboratory	"oil" .00001-1.0 ml/l; most used .001-1. ml/l	(.01-1000. ppm)	5 days	death 1 ml/l. (1000 ppm) delayed cell division 1.0-.001 ml/l (10-.01 ppm)	Mironov (1970)	does not describe oil used or whether concentrations quoted are soluble or not
Inter-tidal plants surf grass	Phyllospadix torreyii	incident Santa Barbara	weathered crude heavy coating		one tidal cycle	death through coating & abrasion (smothering)	Foster et al (1971)	
Green algae (mid & high inter-tidal	Enteromorpha intestinalis	"	heavy coating various coatings			slight damage except where completely coated	"	most intertidal algae have a mucous coat which sheds oil; high intertidal plants, where oil dried were damaged, season important—i.e. blooms, subtidal plants not affected
	Chaetomorpha aerea	"	heavy coating various coatings					
	Ulva californica	"	heavy coating various coatings			U. californica recovered in 4 months		
Brown algae	Egregia laevigata	"	various coatings			little damage		
Red algae	Porphyra sp.	"	"			killed-holds oil		
Kelp	Macrocystis angustifolia	"	heavy coating			no damage-mucous coat		
"	"	Tampico Maru Laboratory	diesel fuel .01%-1% emulsion	1-100 ppm	7 days	loss of photosynth. ability	North et al (1964)	Tampico Maru spill resulted in kills to members all plyla.
Salt marsh grasses	Spartina townsendii	Incidents: Milford Haven & Torrey Canyon	fresh crude		20 min. after spill	75-100% killed	Cowell (1971)	many other marsh plants studied but not summarized here
	Puccinellia maritima	weathered crude (& dispersants)			8 days			
Macro-phytic algae		Incident: Torrey Canyon	weathered crude & dispersants			algae increased coverage of rocks	Bellamy et al (1967)	oil & dispersants killed herbivores, so algae overgrew rocks

TABLE 6.3-1 SUMMARY OF TOXIC RESPONSES FOR MARINE FLORA (from Moore, et al., 1973)

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE AND REPORTED AMOUNT	ESTIMATED HYDROCARBONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
Phyto-Plankton	Dinobryon Sp. Peridinum Sp.	FIELD (freshwater pond, June-October)	M.S.O. crude 4.5 1/6 diam. test area (film on surface)		117 days whole experiment	growth suppressed	Kauss *et al* (1972)	
"	Tabellaria Sp. Ankistrodesmus spirales	"	"		"	growth stimulated	"	
"	Fragillaria Sp. Ankistrodesmus falcatus	"	"		"	no response	"	volatilization & bacterial degradation
"	Chlorococcum Sp.	LABORATORY	Soluble extract from 50 ml in 1 liter water 0, 25, 50, 75, 100% "saturation"	1-5 ppm 100% "saturation"	10 days	no response	"	
"	Cosmarium Sp.	"	"	"	12 days	growth inversely proportional to % saturation	"	
"	Chlorella vulgaris	"	Soluble extract from 50 ml "Gulf" crude in one liter water 0, 10, 25, 50, 75, 90% "saturation"	"	10 days	growth suppressed	"	suppression attributed to a decrease caused by oil
"	"	"	Benzene	25-500 ppm 500-1744 ppm	10 days 10 days	initial inhibition for 2 days, then growth lethal toxicity	"	4 day $LD_{50} \cong$ 650 ppm (our estimate from Kauss data)
"	"	"	Toluene	25-250 ppm 500 ppm	10 days 10 days	slight inhib. lethal toxicity	"	4 day $LD_{50} \cong$ 175 ppm (our estimate from Kauss data)
"	"	"	O-Xylene	25-50 ppm	10 days	slight inhib. lethal toxicity	"	4 day $LD_{50} \cong$ 70 ppm
"	?	"	7 Alberta crudes concentrations unknown		10 days	2 day inhibition then stimulation	"	
"	Chlorella vulgaris	"	Smiley Colville (an Alberta crude) soluble extract		10 days	slight inhibition over 10 day period		

TABLE 6.3-2 SUMMARY OF TOXIC RESPONSES OF FINFISH (from Moore, et al., 1973)

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE AND REPORTED AMOUNT	ESTIMATED HYDROCARBONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
Atlantic Salmon	*Salmo salar*	Laboratory	Corexit 8666 1-10,000 mg/l complete emulsion		7-14 days	4 day LD_{50} >10,000 mg/l	Sprague & Carson (1970)	authors point out probability of sublethal-long-term effects of oil dispersant at lower conc.
"	"	"	1-10,000 mg/l complete emulsion BP110C B BP 1100 Gulf agent 1009 Naphtha gas Dispersant 88 Dispersol SD BP1002 XZIT x-1-11	2-200 ppm	7-14 days	4 day LD_{50} 1-100 mg/l		authors believe Corexit is microbially degraded; the by-products of this process, either from Corexit or waste from microbes, are toxic after 7 day's building in test tank
"	"	"	1-10,000 mg/l temporary emulsion Bunker C	0-1 ppm	7-14 days	4 day LD_{50} ≥10,000 mg/l 7 day LD_{50} ~2000 mg/l		
"	"	"	Bunker C & Corexit 8666		7-14 days	4 day } 7 day } LD_{50} =100-1000 mg/l		
Flounder (winter)	*Pseudopleuronectes americanus*	"	Bunker C & Corexit 866		7-14 days	4 day LD_{50} >10,000 mg/l 7 day LD_{50} ~ 1000 mg/l		
fresh water fish	*Mugil saliens* *Sargus annularis* *Crenilabrus tenca*	"	"oil" .25 ml/l		"many days" "several days"	no effect	Mironov (1970)	emulsion more toxic than film
Plaice	*Rhombus maeoticus*	"	"oil" 10^{-4}-10^{-5} ml/l		2- days	lethal toxidity to eggs	"	
Shad	*Alosa sapidisuima*	"	Gasoline #2 Diesel fuel Bunker C			LD_{50} 24 48 96 Gas 91 91 - #2 204 167 - C -2,417 1,952	Tagatz (196)	loss of toxicity by evaporation
Mullet	*Mugil cephalus* *Micropogon undulatus*	"	#2 Diesel oil .01-10% emulsified	.002-2 ppm		LD_{50} (48 hrs.) ~420 ppm (acute) LD_{50} (chronic) 42 ppm	Texas Instruments (1971)	safe at 4.2 ppm

TABLE 6.3-2 SUMMARY OF TOXIC RESPONSES OF FINFISH (Cont'd) (from Moore, et al., 1973)

ORGANISM COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDROCARBONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
Roach	<u>Rutilus</u> sp.	Laboratory	cyclohexane benzene methylcyclohexane	10 ppm 10 ppm 10 ppm	3-4 hrs.	lethal toxicity	Nelson-Smith (1970)	
Sunfish		"	Phenanthrene Naphthalene Xylene, toluene benzene, ethylene	4-5 ppm 4-5 ppm 22-65 ppm	1 hr.	lethal toxicity	Wilber (1968)	
Thread herring	<u>Ophistonema onglinum</u>	incident: Ocean Eagle San Juan	crude oil & emulsifiers			95% of schools near spill had lesions	Cerame-Vivas (1968)	

TABLE 6.3-2 (from Moore, et al., 1973)

SUMMARY OF TOXIC EFFECTS OF OILS ON LARVAE AND EGGS OF MARINE ORGANISMS

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE AND REPORTED AMOUNT	ESTIMATED HYDRO-CARBONS IN SOLU-TION	DURATION	RESPONSE	REFERENCE	REMARKS
Plaice	Rhombus maeoticus	Laboratory	"oil" 10^{-4}-10^{-5} ml/l			40 to 100% hatched prelarvae perished	Mironov (1968)	no information on experimental methods
Barnacle	Balanus sp.					Larvae 100 times more sensitive than adults	"	"
Cod and Flounder		Laboratory	Bunker C film - 100 ppm	~0	96 hours	35% pulled in stagnant water, not affected in running water	James (1926) reported in Kuhnhold (1970)	"
Black Sea Turbot		Laboratory	10-100 ppm dispersion of Russian crude	.01 - 1 ppm	2-3 days	100% eggs killed	Mironov (1967) reported in Kuhnhold (1970)	"
Herring		Laboratory	10^3 and $2x10^4$ ppm film		2.5-3.5 days	100% eggs killed	Kuhnhold (1969) reported in Kuhnhold (1970)	"
Cod	Gadus morrhua	Laboratory	extract of Venezuelan oil in water 10^4ppm 10^2ppm extracts of Iranian crude 10^4ppm 10^3ppm 10^2ppm control	 .10ppm .1ppm 10ppm 1ppm .1ppm	100 hours	40% higher mortality than control 10-20% increase in mortality 99% killed 63% killed 33% killed 21% killed	Kuhnhold (1970)	Libyan (high paraffin content) did not cause increases in mortality; 10 day old larvae less sensitive
Cod	Gadus morrhua	Laboratory	extracts of Iranian crude in water 10^4ppm 10^3ppm 10^2ppm 10^3 plus 10-100ppm Correxit 7664 10-100ppm Correxit 7664	 10ppm 1ppm .1ppm control 100-1000 ppm ~0	1-10 days 4.2 days 8.4 days 14 days 14 days 3 to 6 hours no effect	Time to death for larvae exposed for 1 day	"	Young larvae less resistant than embryo; Herring less resistant; Plaice more resistant; Libyan crude affected larvae more than embryos

TABLE 6.3-3 (from Moore, et al., 1973)
SUMMARY OF TOXIC EFFECTS OF OILS ON LARVAE
AND EGGS OF MARINE ORGANISMS (Cont'd)

ORGANISM		EXPERIMENT TYPE	SUBSTANCE AND REPORTED AMOUNT	ESTIMATED HYDROCARBONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
COMMON NAME	SCIENTIFIC NAME							
Plaice	Pleuronectas platessa	Laboratory	0 - 10 ppm BP1002	0 - 2 ppm	1-30 days	10 ppm BP1002 killed 100%; 2.5 ppm BP1002 reduced survival by 50%	Wilson (1970)	see original article for considerable more detail; some mortality delayed due to effects on feeding and larval development
Barnacle	Elminius modestus	Laboratory	0 - 100 ppm BP1002 1000 ppm Kuwait	0 - 20 ppm 1 ppm	various	0 - 3 ppm BP1002 increase mortality some reduction of activity	Corner, et al (1968)	original article contains much more data on other dispersants and other tests; adults resistant up to 100 ppm BP1002
Pilchard	Sardine pikhardus	Torrey Canyon Incident	Kuwait and emulsifiers			50-90% of eggs in plankton tows dead	Smith (1968)	
Lobsters	Homarus americanus	Laboratory	.001 - .1 ml/1 Venezuelan crude	(.01-1 ppm)	24-96 hrs.	$96LD_{50}$ = .03 - 002 ml/1	Wells (1972)	.001 ml/1 had little effect; .1 ml/1 very toxic
Sea Urchin	Strongylocentrotus purpuratus	Laboratory	extracts of 25ml crude and bunker C oils in 500ml sea water 6.25% - 50% dilutions	(.1-1 ppm)		fertilization not affected; lowest dilutions interfere with fertilized egg development	Allen (1971	Urchins generally very sensitive
Polychaete	Sabellaria spinulosa	Laboratory	.5 - 1 ppm BP1002	.1 - .2 ppm	several hours to several days	1ppm caused 100% mortality; .5ppm caused abnormal development	Wilson (1968)	death definitely due to kerosene solvent in BP1002
Crustaceans	several	Laboratory	1 - 10 ppm BP1002	.2 - 2 ppm		1ppm BP1002 lethal	Portmann & Connor (1968)	Larvae 10-100 times as sensitive as adults
Oysters	Crassostrea gigas	Laboratory	various detergents 0 - 3 ppm	0 - .5 ppm	24 hours	3ppm of all detergents toxic	Smith (1968)	also similar results for many other marine invertebrate larvae

TABLE 6.3-4 SUMMARY OF TOXIC RESPONSES TO OILS OF PELAGIC CRUSTACEANS
(from Moore, et al., 1973)

ORGANISM COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDROCARBONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
Copepod	several species	Laboratory	.001-.1 ml/l "oil"	(possibly 1-100 ppm)		insensitive to .001 ml/l, 100% death with .1 ml/l	Mironov (1969), cited in Mironov (1970)	experimental methods not described
Shrimp	*Penaeus* sp. *Palaemonetes* sp.	Laboratory	crude oil plus emulsifiers (1-100 ppt)	(1-100 ppm)	"	48LD$_{50}$ = 1-40 ppt crude oil 48LD$_{50}$ = .5-5 ppt crude plus Corexit	Mills and Culley (1971)	see reference for detailed breakdown; oils with higher proportion of aromatics most toxic
Copepod	*Calanus finmarchicus*	Laboratory	1-50 ppm BP 1002 Gamlen Dasic Nolyslip Houghton Solvent 112	.2-10 ppm	1 hour-3 days	50 ppm detergent caused 100% mortality in an hour; 5-10 ppm detergents caused high mortality in 3 days; 1 ppm was injurious	Smith (1968)	
Copepod	*Acartia clausi*	Laboratory	5-100 ppm BP 1002 Dasic	1-20 ppm	10-1000 minutes	lethally toxic at all concentrations	"	BP 1002 5 times as toxic as Dasic; *Acartia* much less resistant than *Calanus*; suggests small animals toxicity is related to size
Pink Shrimp	*Pandalus montagui*	Laboratory	BP1002		48 hr. LD$_{50}$ = 5.8 ppm	Portmann and Connor (1968)		

TABLE 6.3-5 SUMMARY OF TOXIC RESPONSES OF GASTROPODS (from Moore, et al., 1973)

ORGANISM: COMMON NAME	ORGANISM: SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDRO-CARTONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
Dog Whelk Periwinkle	Nucella lapidus Littorina littorea	Incident	"dispersants"			more resistance than crustaceans	Shelton (1971)	Gastropods can produce copious mucus secretion
Periwinkle	Littorina littorea	Incident: Arrow	Bunker C			ingestion of oil--no effect	Scarratt et al (1970)	intertidal contact with oil-oil passed through digestive system unmodified - no uptake in other organs
Periwinkle	Littorina littorea		fresh crude oil			"sensitive"	Nelson-Smith (1967)	
Limpets	Acmea sp.	Incident: Santa Barbara	weathered crude oil	heavy coat		little damage	Foster, et al (1971)	limpets appeared to be feeding on oil
Periwinkle " Limpet Dogwhelk	Littorina neritoides Littorina saxatillis Patella vulgata Thais lapillus Gibbula umbillicalis Littorina obtusata	Field	Kuwait crude (fresh) Kuwait crude (weathered) DP 1002 (single in comgination) ~2 liters/m^2		5 min.--6 hours	general relative toxicity to gastropods BP 1002 > fresh>> weathered	Crapp in Cowell (1971)	data difficult to summarize by species; experiments were small scale and contained many uncontrolled variables, making quantification of results difficult
same 6 species as above		Laboratory	BP 1002 BP 1002			toxicity dependent on season: least toxic in winter (water temp. 10°C) highest in summer (water temp. 18°C) BP 1002 much more toxic than BP 1100	"	same comments as above
Limpet Periwinkle Periwinkle	Patella vulgata Littorina littorea Littorina littoralis	Laboratory	various crudes		sprayed on for 1 hr. then washed	1-89% mortality for L. littoralis L. littorea very resistant. P. vulgata very sensitive	Ottway in Cowell (1971)	high mortality correlates with asphaltenes & low boiling compounds (aromatics, especially).

TABLE 6.3-5 SUMMARY OF TOXIC RESPONSES OF GASTROPODS
(cont.)
(from Moore, et al 1973)

ORGANISM COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDRO-CARBONS IN SOLU-TION	DURATION	RESPONSE	REFERENCE	REMARKS
Periwinkle Dog Whelk Top-shell Limpet	Littorina littorea Nucella lapillus Monodonta lineata Patella vulgata	Laboratory	BP 1002 0-100 ppm	0-20 ppm	24 hrs. "	$LD_{50} > 100$ ppm $LD_{50} \sim 100$ ppm $LD_{50} = 100$ ppm $LD_{50} = 5$ ppm	Smith (1968)	intertidal species periwinkles may recover from 100 ppm all detach from substrate before dying
Limpet	Patella vulgata	Laboratory	BP 1002 0-200 ppm	0-400 ppm		96h $LD_{50} = 5$ ppm	Perkins in Carthy & Arthur (1968)	data supports Ottway's conclusions
Periwinkle	Littorina littoralis	Laboratory	BP 1002			24h $LD_{50} = 250$ ppm		
Periwinkle	L. littorea	"	"			24h $LD_{50} = 2000$ ppm		
Periwinkle	L. littorea	"	crude oil weathering BP 1002			weathered oil less toxic than oil & BP 1002		oil weathered for 24h in lab. simulated tidal washing in lab.

TABLE 6.3-6 (from Moore, et al., 1973)
SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BIVALES (SHELLFISH)

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDROCARBONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
Cockles	<u>Cardium edule</u>	Laboratory	detergents	0-20 ppm	variable	$48LD_{50}$ for BP1002 81ppm	Portmann & Connor (1968)	$48LD_{50}$ for man detergents given
Mussel	<u>Modiolus modiolus</u>	Field (Arrow Spill)	Bunker C			oil content 100-125 μg/gm	Scarrat, <u>et al</u> (1970)	incorporation of Bunker C after Arrow Spill
Mussel	<u>Mytilus edulis</u>	Laboratory	BP1002	~.4ppm		$24LD_{50}$ = 90ppm $48LD_{50}$ = 2ppm	Perkins (1968)	
Cockle	<u>Cardium edule</u>	Laboratory	BP1002	~.4ppm		$24LD_{50}$ = 20ppm	Perkins (1968)	
Mussel	<u>Mytilus edulis</u>	Laboratory	0-100ppm BP1002	0-20ppm	24 hours	5ppm BP1002 not lethal in 24 hours; 10ppm BP1002 lethal	Smith (1968)	Also obtained information on sublethal concentrations
			1000ppm crude emulsion	~60ppm		no deaths, but mussels could not attach properly		
Razor clam Queen scallop	<u>Ensis siligua</u> <u>Chlamys opercularis</u>	Laboratory	BP1002			24 hrs. LD_{50}=0.5ppm 24 hrs. LD_{50}=1ppm	"	subtidal speciel
Oysters		Laboratory	BP1002	~2-20ppm		10-100ppm BP1002 lethal	Simpson (1968)	
Cockles	<u>Cardium edule</u>		phenol			$48LD_{50}$ = 500ppm	Nelson-Smith in Hepple (1971)	
Mussle	<u>Mytilus edulis</u>	Laboratory	"laboratory" weathered (24 hours) Arabian crude plus Correxit or Dispersol approximately .5ml/cm^2 + 10% dispersant		4 tidal cycles	no toxicity for crude oil only; 50% mortality with Dispersol plus oil		simulated tidal conditions

TABLE 6.3-6 (from Moore, et al., 1973)
SUMMARY OF TOXIC EFFECTS OF OIL ON MARINE BIVALVES (SHELLFISH) (Cont'd)

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDRO-CARBONS IN SOLU-TION	DURATION	RESPONSE	REFERENCE	REMARKS
Mussels	<u>Mytilus californianus</u>	Laboratory	$0-10^5$ ppm Santa Barbara crude (as surface film)	0-100ppm	34 days	10^4 and 10^5 ppm caused significant mortality	Danter, Straughan, and Jessee (1971)	individual from area (Coal Point) subject to natural seeps possibly less susceptible than those from other areas; data not conclusive
Mussels	<u>Mytilus edulis</u>	Laboratory	1000mg/1 mineral oil (paraffin only)	0	up to 6 days	no mortality	Lee (1972)	primarily an experiment to investigate uptake and incorporation
			1-8mg/1 heptadecane	0	up to 6 days	no mortality		
			100ppm tetralin	100ppm	up to 6 days	toxic		
			1ppm loluene, napthalene, 3,4-benzpyrene	1ppm	up to 6 days	not toxic		

TABLE 6.3-7 (from Moore, et al., 1973)
SUMMARY OF TOXIC EFFECTS OF OIL ON
MARINE BENTHIC CRUSTACEANS

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDROCARBONS IN SOLUTION	DURATION	RESPONSE	REFERENCE	REMARKS
Shrimp	Crangon crangon	Laboratory	various emulsifiers	~1ppm	48 hours	$48LD_{50}$ for BP1002=5.8ppm	Portmann & Connor (1968)	
Shore crab	Carcinus maenas	Laboratory	various emulsifiers	~3ppm	48 hours	BP1002 $48LD_{50}$=15ppm		
Lobster	Homarus gammarus	"	various emulsifiers	~4ppm	48 hours	BP1002 $24LD_{50}$=20ppm		
Barnacles	Elminius modestus	"	1-100ppm BP1002	0-20ppm	48 hours	100% mortality with 100ppm; 5ppm shows sub lethal effect	Corner, et al (1968)	
			100ppm film of Kuwait	.1ppm	24 hours	some inhibition of cirral beat		
Lobsters	Homarus americanus	"	Bunker C and various dispersants		7-14 days	4 day LD_{50} for Bunker C > 10,000 ppm	Scarratt et al (1970)	lobster fishery of Chedabucto Bay not damaged by Arrow spill; lobsters considered very resistant
Barnacles	Balanus balanoids	"	BP 1002	2 ppm		100% survival at 10ppm	Perkins (1968) in Carthy & Arthur (1968)	
Hermit Crab	Eupagurus bernhardus	"	BP 1002	1ppm		96 hours LD_{50} = 5ppm		
Crab	Carcinus maenas	"	BP 1002	6ppm		96 LD_{50} = 30ppm		
Crab	Cancer pagures	"	BP 1002	2ppm		$24LD_{50}$ = 10ppm	Smith (1968)	
Shrimp	Crangon vulgaris	"	BP 1002	4ppm		$24LD_{50}$ = 2ppm		
	Carcinus maenas	"	BP 1002	5ppm		$24LD_{50}$ = 25ppm		

TABLE 6.3-7 (from Moore, et al., 1973)
SUMMARY OF TOXIC EFFECTS OF OIL ON
MARINE BENTHIC CRUSTACEANS (CONT'D)

ORGANISM								
COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDRO-CARBONS IN SOLU-TIONS	DURATION	RESPONSE	REFERENCE	REMARKS
Hermit Crab	Diogenes pugilator	Laboratory	BP 1002	5ppm		24LD$_{50}$= 25ppm	Smith (1968)	
Barnacle	Balanus balanoides	"	crude oil	2ppm		2% is toxic	Nelson-Smith in Hepple (1971)	
many species		Field	Kuwait BP 1002				Crapp in Cowell (1971)	many field experiments and data which is difficult to summarize; data indicates little toxic response of most species to weathered kuwait.

TABLE 6.3-8 (from Moore, et al., 1973)
SUMMARY OF TOXIC EFFECTS OF OIL ON
OTHER BENTHIC INVERTEBRATES

ORGANISM COMMON NAME	SCIENTIFIC NAME	EXPERIMENT TYPE	SUBSTANCE & REPORTED AMOUNT	ESTIMATED HYDRO-CARBONS IN SOLU-TION	DURATION	RESPONSE	REFERENCE	REMARKS
Polychaete annelid	<u>Arenicola marina</u>	Laboratory	BP 1002	6 ppm		96 hr. LD_{50} = 30ppm	Perkins in Carthy & Arthur (1968)	
"	<u>Nereis diversicolor</u>	"	BP 1002	5 ppm		24 hr. LD_{50} = 25ppm	Smith (1968)	
starfish	<u>Asterias rubens</u>	"	BP 1002	6-8 ppm		24 hr. LD_{50} = 40 ppm 96 hr. LD_{50} = 30 ppm	Perkins in Carthy & Arthur (1968)	
Ane mones	2 species	"	"	5-10 ppm		24 hr. LD_{50} = 25-50ppm	Smith (1968)	
starfish	<u>A. rubens</u>	"	"	5 ppm		24 hr. LD_{50} = 25 ppm	"	
Brittlestar	<u>Ophiocomina nigra</u>	"		1 ppm		24 hr. LD_{50} = 5ppm	"	
Coelenterate	<u>Tubularia crocea</u>	"	crude 0.1-5%			"quickly lethal"	Nelson-Smith in Hepple (1971)	
"	<u>Calliactis parasitica</u>	"	BP 1002	5 ppm		24 hr. LD_{50} = 25	Smith (1968)	
Sandworm	<u>Nereis virens</u>	"	"BP"			96 hr. LD_{50} = 165ppm	LaRoche <u>et al</u> (1970)	only code names of 10 dispersants are given. Sandworm is one of most valuable marine products in New England
"	"	"	"crude oil B"	0		96 hr LD_{50} = 6100ppm		
Polychaete annelids	<u>Cirriformia tentaculata</u>	Incident: shore terminal spill	fresh fuel oil coating on mud surface			little damage	George (1970)	Mucus secretions of worms and inability of oil to penetrate mud may have prevented toxicity
"	"	"	fuel oil & Essolvene			high mortality	"	oil may have been dispersed into mud by emulsifier and ingested by worms
"	"	Laboratory	BP 1002 Essolvene Corexit 7664		<u>C. tentaculata</u> <u>C. cirratus</u> 24 hrs.	24 hr. LD_{50} (ppm) <u>BP</u> <u>Essolvene</u> <u>Corexit</u> 30 63 100,000 129 162 100,000		
Coral	several species	Laboratory	Corexit (0-500 ppm) crude oil 0-500 ppm (slick) & mixtures			harmful at 100-500 ppm (not necessarily completely in solution) dispersant more toxic than oil	Lewis (1971)	crude oil concentrations given were not completely dissolved

TABLE 6.3-9 Summary of Toxicity Data
(adapted from Moore et al., 1973)

Class of Organisms	Estimated Concentration (ppm) of Soluble Aromatics Causing Toxicity
Flora	10–100
Finfish	5–50
Larvae (All Species)	0.1–1.0
Pelagic Crustaceans	1–10
Gastropods (Snails, etc.)	10–100
Bivalves (Oysters, Clams, etc.)	5–50
Benthic Crustaceans (Lobsters, Crabs, etc.)	1–10
Other Benthic Invertebrates (Worms, etc.)	1–10

differentiation may be hypothesized and is convenient, it is difficult to justify on the available data, which contains large levels of uncertainty. Furthermore, no such differentiation can be made for the other categories of oil effects.

An alternative aggregation adopted herein is to consider only two categories of marine organisms--adults and larval stages. The available data (see, in addition to the foregoing taken from Moore, et al., 1973; NAS, 1973; and especially Anderson et al., 1973) indicate that for these two groupings direct lethal response can be expected in most adult marine species from exposures to 1-100 ppm total soluble aromatic hydrocarbon-derivatives for periods of a few hours or less and that larval stages are apparently sensitive to concentrations as low as 0.1 ppm SAD.

6.3.2 Sub-Lethal Effects on Behavior (adapted from Moore, et al., 1973).

Most marine organisms depend upon a complex set of behavioral characteristics to maintain a normal life pattern. Many of these behavioral patterns, especially feeding and reproduction, involve communication based on chemical cues called pheromones. Chemical communication has been extensively studied in insects, but only recently has significant attention been given to marine animals. However, sufficient information is available to draw tentative conclusions regarding the possible effects of oil on chemical communication.

Early studies by several investigators (see Hasler, 1970) focused on migration habits and territory recognition by fish, especially salmon. More recent work has focused on feeding, reproduction and social behavior in fish and lobsters (Todd, et al., 1972). In addition, Whittle and Blumer (1970) have investigated the role of pheromones in predation by starfish.

Extrapolation of the results of these laboratory experiments to natural environments is extremely difficult (probably more so than toxicity tests). The objective of the experiments is to assess behavioral characteristics, but the organisms are placed in very "unnatural" environments,[1] which likely disrupt behavior in themselves. In addition, the chemical clues are apparently extremely subtle and occur in very low concentrations, which makes their identification difficult. Introduction of foreign substances may in fact block these communication signals, but the foreign chemicals may also induce other behavioral responses, only indirectly disrupting normal communications.

The most remarkable part of the utilization of pheromones is that they are recognized at extremely low concentrations. Whittle and Blumer (1970) found starfish react to oyster extracts in concentrations of parts per billion. Apparently, some marine animals have extremely sensitive olfactory and taste organs. More remarkable is the specificity of some animal's response, differentiating among a myriad of compounds in sea water.

One of the most significant set of studies has been carried out by Todd, et al. (1972), examining the bullhead fish which has an extremely complex set of social behaviors. The bullhead is capable of differentiating between species and can even recognize individual fish--making paring relationships possible. Many fish which live in schools have no individual relationships or social structure. However, the bullhead lives

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[1]Todd, et al. (1972) have attempted to alleviate some of these problems by using large aquariums and several species of organisms simultaneously.

in communal life with clear social functions among dominant and subordinate individuals.

Todd attributes this highly complex behavior to subtle chemical clues. He has found that the bullhead brain has enlarged olfactory (smell) lobes and performs a highly integrative function for the senses. Other fish have less developed olfactory areas, and less complex behavior. He concludes that complex behavior is related to highly developed capability of smell, although taste is basically utilized for feeding function. To test this hypothesis the olfactory and the taste organs were destroyed and the bullhead's behavior analyzed. The results show that the bullhead suffered marked loss of the capability of social behavior (mates were attacked and unrecognized) when the olfactory area was destroyed. This indicates significant dependence on chemical clues to maintain complex behavior.

In experiments with lobsters, Todd found that lobsters were attracted and then repulsed by soluble aromatic components of kerosene but that straight chained paraffins had no noticeable influence. Kerosene and the branched and cyclic paraffins induced searching and feeding behavior. Kerosene, polar aromatics, and branched cyclic fractions also initiated agitated grooming behavior. Conceivably, lobsters could be attracted to an oil spill because of the polar aromatic component and the other components of crude oil could disrupt social organization and individual behavior patterns, or even cause lethal or sub-lethal effects from exposure.

Todd has postulated an inverse relationship between physiological toughness and behavioral complexity, i.e., the more complex the behavior patterns for a fish, the lower the adaptability (resistance) to stress (pollution). The most complex behavioral species will have difficulty producing highly resistant strains in a stressed area, i.e., the adaptation of these species will take place but not as successfully as species with simpler (less complex) behavior patterns. Moreover, Todd expresses the proposition that there is a relationship between increased behavioral complexity and ecological complexity. The most complex behavioral species appear in the most complex ecosystems. Therefore he postulates the vulnerability of an ecosystem to stress is related to behavioral complexity, i.e., there is increased vulnerability of an ecosystem with increasing numbers of behaviorally complex species which tend to appear in more complex ecosystems.

The validity of these conclusions is uncertain without more data. It is evident that individual species dependent upon many chemical clues to maintain complex behavior are particularly vulnerable (if Todd's experiments can be generalized), but there is no indication that they are less able to adapt over time to environmental changes than behaviorally less complex species. In fact, population and community level survival may be enhanced due to behavioral complexity. A mature ecosystem typically contains behaviorally complex species and is usually more diverse than juvenile ecosystems. Although it may contain a larger number of individually vulnerable species, the mature ecosystem, because of its diversity of animals and plants, could be better able to withstand stress than less mature and less diverse systems.

In reviewing the field of chemical communication in marine organisms, and assessing their vulnerability to crude oil a few conclusions can be drawn. However, they must be tempered with the realization that the field is not extensively developed and most of the experiments are preliminary.

Field conditions may considerably alter behavioral responses and circumstances of exposure, thus either enhancing or diminishing effects while revealing new problems. Moreover, higher boiling hydrocarbons have not been used in any experiments, and it is this portion of crude oil that is the long term contaminant of the environment.

Apparently, disruption can occur from relatively low concentrations of petroleum substances (10-100 ppb). However, the toxic properties of the low boiling component may be more important than the chemical communication disruption. More importantly it is unclear whether the behavioral changes that might occur can lead to permanent damage to individuals and populations.

The extent of chemical communications in marine animals is substantial and plays an essential role in behavior. Although the present evidence for the effects of crude petroleum on chemical communication is limited, the long term effects related to successful adaptation or survival could be serious. Any introduction of large quantities of hundreds of chemical compounds should be a cause for concern, requiring both accelerated experimentation examining possible consequences and a sense of caution in decision-making regarding any new possible modes of release into the marine environment.

6.3.3 Incorporation of Hydrocarbons

Tainting and accumulation of hydrocarbons in organism tissues occur in many, if not all, marine species. Essentially any aquatic organism can be expected to equilibrate chemically with its surrounding media. If the media contains even low (ppb) concentrations of hydrocarbons, these substances may be injested and accumulate in various tissues. For example, Burns and Teal (1971) have shown that oil entering a salt marsh can be found in virtually all organisms examined. If exposure is terminated, depuration occurs (Anderson, et al., 1973) to some extent in at least some bivalves and probably other species. However, this is a little studied phenomena for other than commerically important bivalves. In addition, Blumer (1970) reports data indicating only limited depuration occurred in bivalves exposed to oil continuously for several months following the West Falmouth oil spill. Numerous other investigators have reported data relating to tainting (Blumer and Sass, 1970; Lee, et al., 1972; Mackin, 1961; Nelson-Smith, 1971; Tarzwell, 1971; Wilder, 1970; and Sidhu, et al, 1970).

6.3.4 Coating and Habitat Alteration

Coating effects, which are principally associated with the higher boiling fractions of oil (weathered oil), are primarily a problem for intertidal sessile species, plankton and diving birds. Mobile organisms can normally avoid exposure (Nelson-Smith, 1973) and sub-tidal benthic species are protected because the oil does not occur as a film subtidally. The necessary thickness of coating to cause mortality is not readily definable. However, most species exposed to a coating of weathered crude oil are likely to be effected. A more detailed discussion of coating problems appears in Moore et al. (1973).

The effect of habitat alteration is, of course, to prevent species normally present in or on a substrate from inhabiting the area. Intertidal and sub-tidal benthic species are therefore of primary interest. The amount and composition of oil necessary to prevent a species from utilizing a substrate is largely unknown. In light of available toxicity data, the presence of low to medium boiling point aromatic hydrocarbons as concentrations as low as 10-100 ppb may be chemically insulting to virtually all relevant species. The presence of higher boiling, insoluble materials may or may not effect a species depending on the organisms reliance on the specific physical nature of the substrate and the degree to which this is altered by the presence of oil.

Species dependent on a substrate only for passive support, that is, those simply lying <u>on</u> the substrate, may be little affected by the physical presence of oil. However, species living <u>in</u> the substrate (infauna), or otherwise more than passively dependent upon the substrate can be expected to be more vulnerable to this effect. Unfortunately, there is virtually no data on the relationship between the amount of oil present and the degree of suitability of the substrate for various species.

In light of the discussion in Chapter 5 habitat alteration effects may persist over time periods of 3-10 years or more depending on the specific habitat exposed.

6.4 Sensitivity of the Selected Species of this Study

A principle characteristic of this study is analysis of particular selected species. However, the foregoing section (6.3) suggests that available data is insufficient to reliably identify sensitivities of even gross groupings of species to various effects of oil. As further illustration of this problem Table 6.4-1 summarizes data reported on effects of oil for the particular species selected for analysis in this study (see Chapter 4). Although specific references have not been cited in Table 6.4-1, the literature covered includes all of that previously cited in this chapter, including the extensive reviews by Nelson-Smith (1973), Clark (1971), and NAS (1973). In short a large body of literature has been searched. It is immediately apparent that relatively little is

TABLE 6.4-1

Selected Species for Which Some Data on Effects of Oil Have Been Reported[1]

Species[2]	Common Name	Lethal	Sublethal	Coating	Uptake and Tainting	Habitat Change
BIRDS:						
Rissa tridactyla	kittiwake			✓		
FISHES:						
Alosa spp.	alewife	✓				
Clupea harengus	herring	✓				
Fundulus heteroclitus	mummichog	✓				
Gadus morhua	atlantic cod	✓				
Micropogon undulatus	croaker		✓			
Morone saxatilis	striped bass		✓			
Pseudopleuronectes americanus	winter flounder	✓	✓			
CRUSTACEANS:						
Acartia spp.	zooplankter	✓				
Ampelisca vadorum	amphipod	✓				✓
Balanus balanoides	acorn barnacle	✓				
Calanus spp.	zooplankter	✓			✓	
Crangon spp.	shrimp	✓				
Emerita spp.	mole crab	✓				
Homarus americanus	american lobster	✓	✓			
Pagurus longicarpus	hermit crab	✓			✓	
Pandalus spp.	shrimp	✓				

1 - A check (✓) in the table does not imply extensive, valid data is available for the particular effect on the specified species, only that some data has been reported.

2 - Only species given in selected species list of Chapter 4 are included here.

(CONTINUED ON NEXT PAGE)

TABLE 6.4-1 (Cont'd)

	Common Name	Lethal	Sublethal	Coating	Uptake and Tainting	Habitat Change
MOLLUSKS:						
Aquipecten irradians	scallop	✓	✓		✓	
Crassostrea virginica	virginia oyster	✓	✓		✓	
Donax emeritus	coquina clam	✓				
Mercenaria mercenaria	northern quahog	✓				
Modiolus demissus	horse mussel		✓		✓	
Mya arenaria	soft-shell clam	✓			✓	✓
Mytilus edulis	edible mussel	✓	✓	✓	✓	
Littorina littorea	periwinkle	✓	✓	✓		
Nassarius obsoletus	common mud snail		✓			
Thais lapillus	dog whelk	✓	✓			
WORMS:						
Arenicola marina	lugworm	✓	✓			✓
Nereis virens	clam worm	✓				
Streblospio benedicti	ploychaete	✓				
OTHER ANIMALS:						
Asterias vulgaris	starfish				✓	
Strongylocentrotus droebachiensis	sea urchin	✓			✓	
PLANTS:						
Juncus gerardi	marsh rush	✓				
Spartina alterniflora	marsh grass	✓			✓	
Spartina patens	cord grass	✓				
Laminaria spp.	kelp	✓				

known about the effects of oil on a species-by-species basis. The problem is not a product of the particular species selected. In fact, those species listed in Table 6.4-1 include some of the most frequently studied species. In addition, even though we undoubtedly have not reviewed every published article on the subject, it is extremely unlikely that the large gaps in information can be filled from lesser known, obscure publications.

Finally, and most importantly, the summary presented in Table 6.4-1 does not indicate the limited nature of the data that is available. A check (√) in Table 6.4-1 merely implies some, no matter how little, data have been reported. In fact, as discussed in Section 6.3 much of the data that is available is of questionable value. As a result, some amount of aggregation is necessary to make an assessment of individual sensitivities possible. However, the dangers of lumping and generalizing must be explicitly kept in mind.

6.5 Summary

In the preceding sections the biological effects of oil on individual organisms have been reviewed. Several important considerations are apparent from this review:

1. As many authors have noted, the soluble aromatic fractions of oil pose the most serious environmental problems. Although low molecular weight (10 carbons or less) alkanes can cause narcosis, the concentrations required to induce such responses are extremely high and would not occur from an oil spill.

2. Concentrations of water-soluble aromatic derivatives (aromatic and naphtheno-aromatics) as low as 0.1 ppm may be toxic to larvae of most marine organisms.

3. Most adult marine organisms are sensitive to soluble aromatic

derivatives in concentrations of 1 ppm and lethal toxicity typically occurs at concentrations of 10-100 ppm.

4. Chemical communications play an important role in the behavioral patterns of many marine organisms. The full implications of disruption of these communication patterns remain uncertain, as does the exact mechanisms of disruption. However, concentrations of soluble aromatic derivatives in the range of 100-100 ppb may cause significant problems.

5. The incorporation of hydrocarbons in the tissue of marine organisms can apparently result from very low ambient concentrations in water. If the contamination in the water is short-lived and concentrations in water are not too high, self-cleansing of the organism may be nearly complete. However, the maintenance of undesirable water conditions over longer time periods may result in permanent contamination of the organism.

6. Weathered oil may lead to coating, in the intertidal zone, of both organisms and substrates. If coating is heavy, the effects may be essentially permanent, smothering individuals and/or altering substrate textures. Frequency of coating is important and areas subject to chronic discharge may accumulate the oil, leading to longer term problems.

6.6 References

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CHAPTER 7

POPULATION AND COMMUNITY RESPONSES TO OIL

7.1 Introduction

Effects of oil discharges resulting from offshore petroleum developments on populations and communities in marine ecosystems is of ultimate primary interest. Lethal and sub-lethal effects on individuals, such as discussed in Chapter 6, take on significance (except for the specific organism(s) affected) only in so far as changes are detectable in a population or assemblage of populations (community). Population size and age-distribution are principal measures of a species as a resource in an area. Because these population characteristics depend on the aggregation of individual births, deaths and migrators in the area of interest, population sensitivity to oil may differ significantly from that of an individual. For example, a population widely dispersed spatially consisting of very sensitive individuals may also have a high reproductive rate and effective dispersal mechanism, and therefore may be relatively resistant to detectable effects of oil spills. That is, a population may have an effective mechanism (strategy)--high birth and immigration rates--to counter an unexpected high death rate. In order to predict population level effects of oil, it is necessary to translate individual responses and sensitivities into changes in population birth, death and migration rates which exist in the absence of exposure to oil. This chapter attempts to analyze this essential, but little-studied problem. The even more difficult problem of translating population level effects into community responses is treated briefly, in the context of interspecific relationships associated with specific populations (selected species). However, comprehensive community models and/or models of community diversity--number and composition of species--are not developed.

7.1.1 Accidental and Continuous Discharges

Development of offshore petroleum resources may result in two distinctly different types of oil discharges, each with significantly different biological effects. One type is accidental spills--discrete events causing sudden, large perturbations of the environment.

Three environmental conditions associated with accidental spills can be identified: pre-spill "equilibrium," immediate post-spill impact, and recovery from impacted conditions back to an "equilibrium" condition. Pre-spill "equilibrium" is a dynamic condition of a habitat in which species' numbers, population densities and age-structure remain within identifiable bounds. Population birth, death and migration rates are in balance over time periods measured on the order of years. The immediate potential impact of a spill is an immediate but short-lived (by definition) increase in population death rates. Magnitudes of mortality depend on the nature of the exposure and sensitivity of individuals exposed (Section 7.2). Recovery from an accidental spill involves dispersion and degradation of spilled oil and return of populations to "equilibrium" conditions (Section 7.3). During recovery population birth, death and migration rates are, by definition, not in balance. The time period necessary for recovery is a critical parameter in determining the ultimate environmental effects of an accidental spill (Section 7.4).

The other genre of discharge is continuous, or nearly continuous, releases of oil to the environment (Section 7.5). In general, continuous spills are effluents from sources such as oil-water separators, consisting of low concentration, oil-contaminated water which do not elicit the impact-recovery response of accidental spills. Such releases do not have dramatic sudden impacts, but instead may cause subtle changes in birth, death and migration rates which are only differentiable from natural population fluctuations after long time periods with many years of data.

Oil deposited in inter- and sub-tidal substrates following an accidental spill may be a continuous spill source due to slow and continuous release of oil fractions from the sediments (see, for example, Thomas, 1973). However, the most significant continuous spill sources are intentional discharges from operations necessary for petroleum resource development. Regulatory authority exists with EPA to control discharges of waste streams containing low concentrations of hydrocarbons and other pollutants associated with petroleum development activities.

7.1.2 Population Models and Data

Ostensibly the objective of the ensuing sections is to develop models useful for predicting population effects of hypothetical accidental and continuous spills. Although mathematical models dynamically describing population density and age-structure and embodying birth, death and migration rates as a function of oil exposure are most desirable, several sources of uncertainty and information gaps prevent development of such models.

Chapter 6 documents the many levels of uncertainty regarding responses and sensitivities of individuals. Correspondingly, useful functional relationships between birth, death and migration rates and oil fraction concentration are not available. Moreover, as discussed in Chapter 4, relatively little data exist describing natural birth and death rates for even the well-studied species selected for this study. Furthermore, virtually no data exist from which birth, death and migration rates during recovery can be deduced. Observations of recovery from the Torrey Canyon, Tampico Maru, and West Falmouth spills provide some indication of recovery patterns, but estimates of population birth, death and migration rates are not extractable from the data.

In the absence of previous useful models and reliable data to develop and verify new models, several options are available. On one extreme further analysis of the problem can be ignored. On the other extreme, theoretical, unverified mathematical models can be developed and applied. A middle ground, pursued herein, consists of formulation of conceptual, largely qualitative models which have some theoretical basis, but are not thoroughly verified. The results provide some insight to the population level problem, indicate more precisely present data needs and establish a departure point for developing better models. Many implicit and explicit assumptions are made, some of which are convenient but known to be unrealistic. The results must be viewed with due caution.

7.2 Accidental Spill Model: Initial Impact

An idealized conceptualization (model) of the behavior of total population density effected by an accidental oil spill is shown in Figure 7.2.1. Two distinct problems are identified: initial impact and recovery. In Section 7.3, models of recovery for various types of species are presented. In this section a model is presented of initial impact of an ac-

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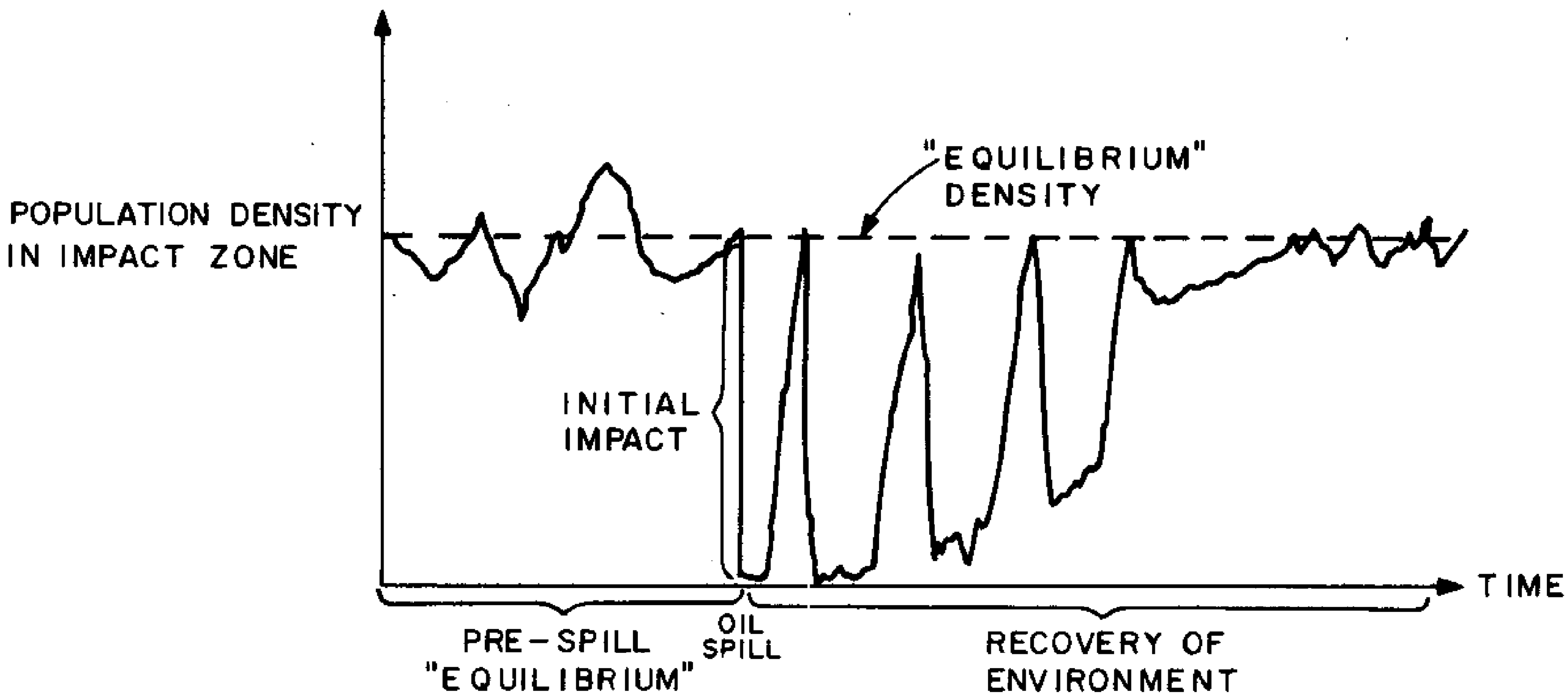

Figure 7.2-1. Idealized conception of recovery process. Time scale is arbitrary. See text for discussion.

cidental spill on a population.

The initial impact of oil on a portion of the environment depends on the nature of oil exposure and the sensitivities to that exposure of individual organisms present in the impacted zone.

Actual oil exposure resulting from a spill is characterized by several parameters:

1. Oil composition - the relative and absolute amounts of various hydrocarbon fractions; of particular interest is the concentration of lower boiling (<250^{o}C) aromatic hydrocarbons.
2. Oil amount - actual volume of oil impacting an area; thickness and areal extent of slicks, patches, etc.
3. Degree of coverage - geographical; the percentage of area covered with oil and distribution of oil coating within the area of interest.
4. Meteorologic/oceanographic conditions - sea conditions - waves, surf, etc. - important in determining the extent to which oil is mixed in the water column and into sediments.

Given the large biological uncertainties, it is unrealistic to attempt to definitively describe a particular hypothetical spill in terms of the above parameters. However, as described below, broad categories of definition such as weathered/unweathered are useful in obtaining rough estimates of possible initial impacts.

Based on the discussion in Chapter 6 of sensitivity of individual organisms to oil, the following approximate characterization is made:

1. unweathered crude oil, as defined in Chapter 5, can be assumed to contain sufficient low boiling toxic fractions to cause mortality in most marine organisms exposed to the slick;
2. coating by the main body of a slick or by patches of weathered oil is likely to kill most sessile species and to alter any substrates covered;
3. sub-lethal effects due to accidental spills cannot be accounted for in most situations;
4. hydrocarbon incorporation is likely to occur in most species, especially filter feeders, from exposure to all but residual fractions. The degree of incorporation of tarry, residual substances is unknown.

The percentage of a population within a habitat or region killed or otherwise effected by a spill depends on the parameters described above. Although estimating such percentages is extremely difficult, if not impossible at least the problem is bounded by two real cases: the no kill situation - zero recovery time; and the 100% mortality situation - maximum recovery time required. For any case expected to be in between these extremes, i.e., partial mortality, definition of initial impacts is complicated because both reduction in population size (density) and alteration of age-structure must be accounted for. Realistic estimates of such changes are virtually impossible to make, and analysis of subsequent recovery is equally difficult. For the most part then, recovery analysis which follows is confined to worst case situations of 100% mortality. Uncertainties aside, this is a useful exercise, establishing a worst case condition.

In Chapter 8 the foregoing discussion serves as a basis for estimating initial impacts of specific hypothetical oil spills occurring at platforms and terminals.

7.3 Accidental Spill Model: Recovery

The total recovery process can be partitioned into two overlapping time periods: 1) the time required before the physical substrate is suitable to permit recolonization; and 2) the time required for a species to recover in terms of density and age-distribution. The former problem of oil persistence is discussed in Chapter 5. The latter problem is discussed below.

Four classes of recovery or recovery "strategies" are defined based on the dynamic processes contributing to population return to "equilibrium." In only one case can recovery time be estimated. The other three cases are qualitatively discussed and important features of recovery for such species identified. In Section 7.4 each selected species for each habitat in each sub-region (Chapter 4) is placed in one of the four recovery classes and then overall habitat recovery is considered.

7.3.1 Analytical Framework

The total number of species (populations) within a single habitat is unworkably large for a species-by-species treatment in this study. Therefore, selected species have been singled out for study (Chapter 4). Analysis of the response to and recovery from oil by these species, within a particular habitat, is arbitrarily assumed to be sufficient to gain insight to recovery processes and to compare biological vulnerability of various habitats and regions to oil spill impacts.

A thorough approach to the recovery problem would require an understanding of the interrelations among various species as well as the internal dynamics of each population. As pointed out in Chapter 4, little of the necessary quantitative information is available to assess intra- or inter-species phenomena. Such fundamantal population level data as natural population density, average fecundity, in-situ age-specific mortality, and longevity, and such inter-species level data as identity and intensity of predators, competitors, and commensals are very hard to come by. It is quite apparent that in order to escape the realm of guesswork in the future, much basic biological research is necessary.

However, at least some data on many species are available. The authors have deemed it appropriate, therefore, to postulate general classes of recovery strategy, classes with sufficiently broad bounds that even a sketchy description of a species' characteristics will suggest its class of recovery strategy. These classes are distinguished by their different modes of colonization and expansion in unsettled, hospitable habitats. Each class requires a different form of analysis, a format which will be applicable to all member species in that class.

The various classes of recovery (i.e., colonization) strategy which are identified are presented diagrammatically in Figure 7.3-1. The schematization is inspired by the work of Gunnar Thorson, especially Thorson (1950), in which he discusses the various larval life histories of marine organisms. This discretization is justified by the conceptualization of recovery processes presented below.

There are four events which comprise the recovery process of a population whose ranks have been reduced by oil (or any other catastrophe).

1. Recovery begins with survivors. Some fraction $0 \leq f < 1$ of the original population within boundaries of interest survives the spill. (Note that f may be zero—the 100% mortality case.)

2. Colonizers enter recovery area. Immigrants, usually larvae or other new-born, disperse in their own particular manner into and within

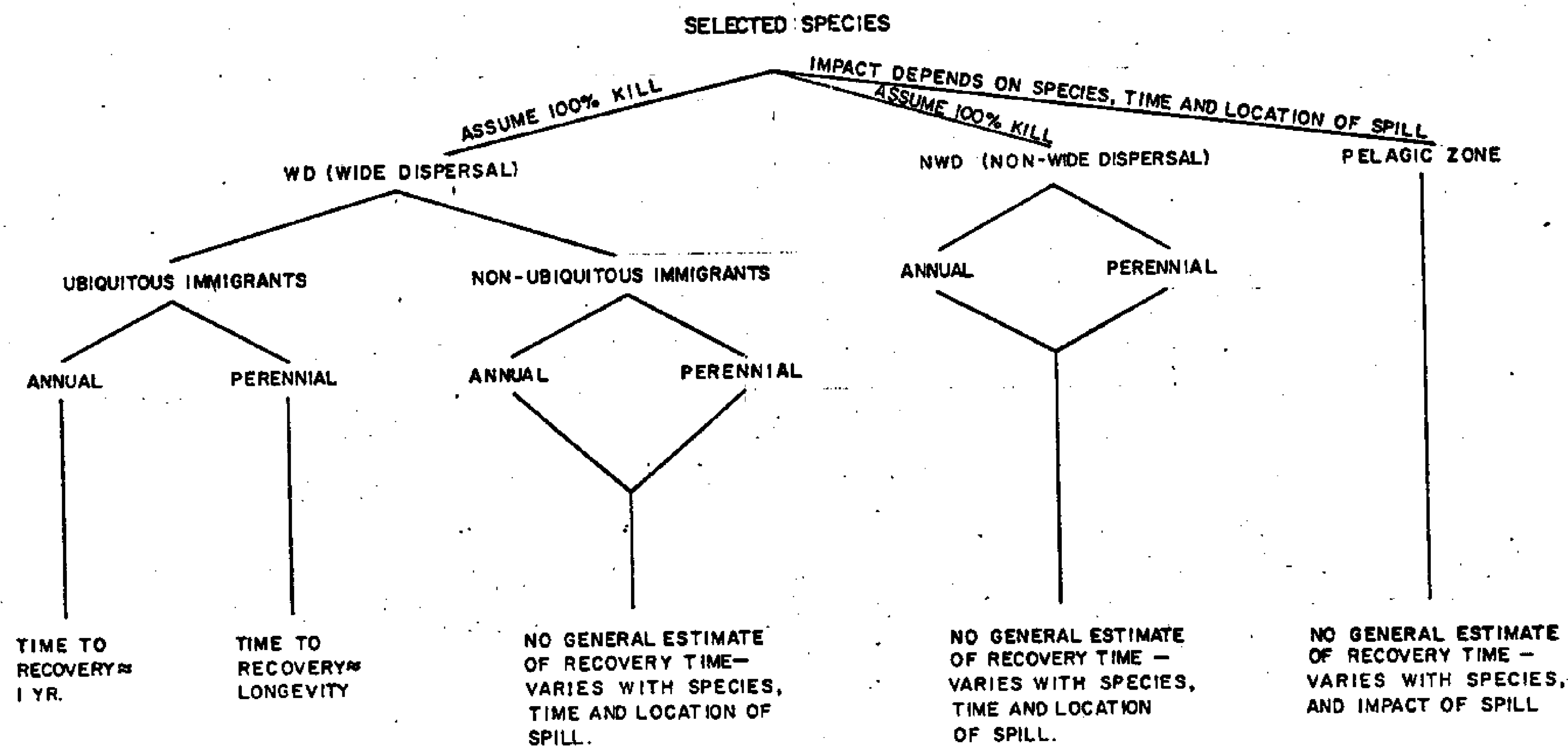

Figure 7.3-1. Recovery strategy categories and estimated recovery times in uninhabitated, hospitable environment.

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the habitat. Two classes of dispersal--wide and non-wide--are identified. Wide dispersal (WD) species are defined in the sense that if the entire spatial extent of a species' pre-spill habitat is (equally) accessible to re-invading members of the species, then the species is a wide dispersal species. Species whose dispersal is limited, so that areas of a habitat under consideration cannot be reached by colonizers in a single reproductive season, are considered non-wide dispersal (NWD) or incremental growth species (Section 7.3.4). One can imagine that the range of a non-wide dispersal strategist will expand incrementally, "creeping" outward from a pocket of survivors or inward from the edges of the spill. It is evident then that both spatial and numerical recovery must be tracked in the NWD species recovery. This contrasts with the WD species case, where only temporal recovery need be predicted and spatial recovery is assumed uniform (in the sense that all available sites are filled without regard to spatial location. Of course, organisms will not recover in areas which are always unattractive to them.).

A second distinction arises from the question of availability of immigrants (usually larvae) in wide-dispersal species. Are only a few arriving to resettle the area, or are they washing in on the tides in millions? The latter case, where enough immigrants arrive to fill every available site, is termed the "ubiquitous immigrant" case (Section 7.3.2). If there is a shortage of settlers, whether due to limited adult stock in the vicinity, or low fecundity, or unfavorable transport (currents, tides, winds), then this is the "non-ubiquitous" case. This final case--wide dispersal non-ubiquitous--is difficult to analyze due to the uncertainty of immigrant availability (Section 7.3.3). It is, however, an exceptional case for which only a few species qualify, and these are primarily birds.

3. Colonizing individuals settle. After oil has degraded sufficiently to allow successful settlement, colonizers are exposed to the usual physical rigors of the habitat (temperature, salinity, waves), which, however, may be altered significantly in the wake of the spill (e.g., loss of marsh grasses permits wave-induced erosion). They also suffer a milieu of biological pressures which changes continuously with recovery. Predation, parasitism, competition and commensalism during recovery may differ dramatically in intensity and identity from these processes in the established pre-spill habitat.

One logical, comprehensive approach to the changing recovery milieu--an interspecies dynamic model--has been ruled out due to data unavailability. However, this problem is one of succession in marine habitats. Further theoretical treatment of this problem has not been explored in this study, but it deserves attention.

4. Recovery is completed. For annual species recovery is defined as reestablishment of pre-spill population density. For perennial species recovery is equated to regeneration of a pre-spill stable age-distribution within the population. Our rationale for this criterion is simply that a species with a stable age-distribution seems well entrenched in its habitat. Stable age-structure criterion is favored over a minimum density criterion because the latter is even more difficult to define and implement. Natural fluctuations in density are great, and especially in species of commercial importance where age implies size, a recovery criterion ought to reflect age-structure as well as density.

The question of whether natural marine populations ever exhibit stable age-distributions deserves attention. In fact, it would appear that such phenomena as dominant age-classes and highly variable planktonic conditions preclude occurrence of stable age-distribution, at least in WD marine species. Nevertheless, with assumptions on fecundity and mortality, a time to stable age-distribution is theoretically calculable for any perennial species and is considered a working definition of time to recovery.

Figure 7.3.1 indicates one additional class of recovery yet to be discussed: pelagic species. Admittedly, "pelagic species" is not a recovery strategy in the same sense that WD-U or NWD are strategies; it is a habitat sufficiently unique in size and dispersal characteristics to require separate consideration. It is dealt with in Section 7.3.5.

In summary then, the following classes of dispersal (recovery) strategy are defined:

1. wide dispersal--ubiquitous immigrants (WD-U) (Section 7.3.2)
2. wide dispersal--non-ubiquitous immigrants (WD-NU) (Section 7.3.3)
3. non-wide dispersal (NWD) (Section 7.3.4)
4. pelagic species (Section 7.3.5).

Each dispersal type may be either annual or perennial. From available data a species can be placed in one of the above categories. If data permits, an additional distinction concerning age-specific survivorship can be drawn, and then the time to stable age-distribution can be computed for each class of recovery strategy.

Before proceeding to more detailed consideration of each recovery strategy the reader is cautioned to view all computations and other estimates of recovery time with utmost respect for facets of the problem not fully considered. No doubt some people (including the authors) may view with great skepticism estimates of recovery based on a set of assumptions which do not carefully account for interspecies dynamics. Blooms (explosive population growth), inhibiting predation, competition and overgrazing are not modeled--nor can they be in the wide range of cases considered herein. It is assumed that there is always room for a species once decimated to return and recolonize--no other species will usurp its niche and its niche will still exist. Gaining a foothold in the environment is not considered a problem. An organism simply needs time to grow to the proper age and recovery is complete. None of these assumptions are necessarily true. For some species they may not even be useful approximations.

On the other hand, the authors do not view the analysis as useless. The theoretical approximation to recovery processes developed herein is a working hypothesis from which some insight to the problem is gained and more adequate answers to the problem can ultimately emerge. The fact remains, unfortunately, that the data base and knowledge of governing processes is grossly inadequate for drawing definitive conclusions other than the need for additional basic research.

7.3.2 Recovery Model: Wide-Dispersal-Ubiquitous Species

Recovery time from total mortality in a habitat for any Wide-Dispersal-Ubiquitous (WD-U) species is estimated to be approximately the average longevity (life span) of that species. This result is arrived at analytically using simple demographic techniques (Appendix 7-1), but is also intuitively appealing, without recourse to the concept of stable age-distribution and a demographic model. Special-case considerations such as immigrating adults and interspecific relationships, which may alter the estimated recovery time for some species, are also considered.

A model is used in this analysis which is based on a simple life-table type model of age-specific population growth and decay. For computational simplicity, a specific matrix form (Leslie matrix, Emlen, 1973) is used which requires age-specific schedules of survivorship (probability of surviving to each age class) and fecundity (eggs, offspring, etc., produced per female per year in each age-class). In addition carrying capacity (maximum possible population density) must be specified. From these data, given an initial age-structure, the age-structure over time can be estimated (see Appendix 7-1 for model details).

Application of the model has not been made on a species-by-species basis. Rather, for a wide range of hypothetical survivorship curves time to stable age-distribution (recovery time) is computed, assuming an initially decimated population. For survivorship curves typical of WD-U species the time to stable age-distribution is approximately equal to longevity. These results assume a static "equilibrium" survivorship schedule throughout recovery which is unrealistic and leads to a "dominant year-class" phenomenon for all WD-U species. Dominant year-classes, though frequently observed in many species, rarely survive intact and then die off suddenly at the end of their life-span, precipitating the start of another dominant year-class, as predicted by the model.

Intra-specific factors that may influence the time to stable age-distribution for a species are density-dependent phenomena, growth rate and mobility of adults. Density-dependent phenomena for WD-U species are ignored, by definition. For this class of species, density is assumed constant and equal to the "equilibrium" density as soon as recovery begins (see Section 7.3.1 for a justification of this assumption). The model used in this section does not explicitly discuss growth in size of re-established individuals. Growth is assumed commensurate with age, while density remains constant. Lack of time and a need for simplicity are the main reasons for neglecting this inconsistency, as data on growth rates exist for many species. To handle this problem in the future one would have to treat "equilibrium" density as a function of age-specific population. This simplification primarily results in an estimate of a stable age-structure with too many individuals in the later age-classes.

In most WD-U species recolonization will be by species larvae.,i.e., all immigrants are in the o^{th} age class. However, a few WD-U species also have significant adult migration. Adult mobility, if present in a species, can greatly reduce the time required to reach a stable age-distribution (see also Appendix 7-2). For species where adult immigration is possible, the time to stable age-distribution is of the order of one half the average life span, or less.

Major inter-specific effects which may effect recovery time for species include non-equilibrium food, predation and competition conditions, and dependence on a successionally prerequisite species. Interspecific influences of complex food, predation and competition patterns under "equilibrium" conditions are taken into account implicitly by "equilibrium" survivorship rates. Under "non-equilibrium" conditions (such as recovery from an oil spill), transient changes in the community structure of a habitat induce different survival rates in the recovering species.

A more realistic model recognizes the changing biological environment (e.g., type and density of the recovering species, food, predators, competitors, and parasites) during the recovery process. Therefore, survivorship schedules also change with time. Unfortunately, except for barnacles *(Balanus balanoides)* (Connell, 1961), data are not available from which such time-varying survivorship curves can be estimated for particular species. Furthermore, the few accounts of community structure during recovery after a spill (Sanders, et. al., 1970; North, et. al., 1964) do not provide a sufficient basis for predicting overall community structure during recovery, from which "non-equilibrium" survivorship rates can be determined. Consequently, the analysis of recovery time in this section is based on "equilibrium" survivorship values, with the realization that for some species this approach is certain to give erroneous recovery times. As the following examples illustrate, predictions of recovery time not accounting for inter-specific factors are most likely too low.

Several cases have been cited in the literature where inter-species effects have greatly effected the post-spill survivorship of species, seriously delaying recovery:

1. Following the wreck of the Tampico Maru (North, et al., 1964), the kelp *Macrocystis pyrifera* bloomed within four months. The kelp subsequently died down, but has repeated this cycle several times since then. The violent cycles which have been observed since the spill are uncharacteristic of *M. pyrifera* in that area. The cycles are attributed to the large reduction of the sea urchin popu-

lation in the cove, which had previously grazed the kelp to a more stable level.

2. Following the heavy use of dispersants during the Torrey Canyon spill (Smith, 1968), fucoid algae bloomed on rocks where originally limpets and periwinkles, now eliminated, had grazed the algae. Once the algae had covered the rocks of an area, recolonization by limpets and periwinkles was much slower than in areas where a few surviving winkles had kept the algae partially grazed.
3. Soon after the West Falmouth oil spill (Sanders, et al., 1970), intertidal stations where almost all fauna was eliminated saw a bloom of the small worm *Capitella capitata*. Presumably, when competition for resources was temporarily eased, this oil-resistant worm was able to bloom. As soon as other species began to repopulate the area nine months after the spill, *C. capitata* returned to its "equilibrium" density.

Without additional data on species and communities it is not possible to refine predictions of inter-specific relations on recovery. However, assumption of an "equilibrium" survivorship curve throughout recovery is a first approximation, which probably yeilds a minimum recovery time for the worst case condition of 100% mortality. Since "equilibrium" survivorship values can have a broad range, fluctuations in age-specific mortality may average out to fit into that range and show no effect on recovery time.

A recovering species may also require another species to be present in the environment before the recoverer can reestablish. Examples are specialized predators which require their food to be present, and specialized epiphytes which require their substrate to be present. This additional interspecies effect is also neglected as unimportant for most species. Considering the ecology of the WD-U class, one finds that most species are such broad generalists, particularly in their food preferences, that successional order does not delay their recovery. In the cases of the few WD-U species which are not broad generalists, an estimate of possible additional delay can be added to each species recovery time.

To summarize the treatment of the main factors determining recovery-time to stable age-distribution for WD-U species:

1) Based on age-specific survivorship for a wide range of survivorship curves covering all realistic estimates for WD-U species, time to

recovery is approximately equal to longevity.

2) Age-specific fecundity can be ignored by definition of WD-U species.
3) Density-dependent phenomena can be ignored by definition of WD-U species.
4) Growth-rate is omitted for simplicity. However, this omission will only cause a miss-estimate of the stable age-distribution, not the time to reach stable age-distribution.
5) Adult mobility is not applicable to most WD-U species, but can be treated as a special case where relevant. Adult mobility may reduce recovery time to one-half longevity or less.
6) Inter-specific effects during recovery are only treated qualitatively. These effects may cause significant errors in recovery time estimates approximated by use of "equilibrium" survivorship rates throughout the recovery process. It is likely that resulting estimates are too low but the size of any error is unknown.

7.3.3 Recovery Model: Wide-Dispersal-Non-Ubiquitous Species (Birds)

Specific estimates of recovery time from 100% mortality in a habitat for wide-dispersal non-ubiquitous species are not made. Uncertainties in immigrant availability--by definition, non-ubiquitous immigrants--not only make recovery difficult for a particular species, but make development of models difficult. A useful model must explicitly provide functional representations of the relationship between a limited adult stock or offspring production in one area and number of recruits entering another area. Even in relatively well-studied populations, such as certain fisheries, stock-recruitment relationships are poorly known (see, for example, Cushing, 1973). Therefore, this class of recovery is treated quantitatively. Because birds constitute the only selected species which fall into this class, the remaining discussion focuses specifically on avian species.

Atlantic and Alaskan coastal habitats support hundreds of species of birds, providing wintering grounds, breeding grounds, feeding grounds, and migratory routes. Some birds frequent these shores who in other seasons are as far away as the Arctic or Antarctic circles; others have established year-round residences here; still others migrate up and down the coast with the sun, stopping over at a number of different habitats during their journey. A few bird species are selected for consideration in this study.

It is safe to say, however, that marine/estuarine bird populations are in general extremely vulnerable to catastrophic mortality from oil spills (Clark, 1971).

The rationale for this hypothesis, beyond observations, is straightforward. Six factors contribute to the precarious status of bird populations.

1. Bird kills from oil result from coating of the feathers by either weathered or unweathered petroleum. The insulation property of the inner feathers (down) is lost, and the bird literally freezes to death in any season. A bird must either enter oil-slicked water to suffer this fate (diving birds) or move about in a shoreline habitat covered with washed up oil (any shore birds). Diving birds show no awareness of the presence of a slick, dive directly into it, and may perish in great numbers (Nelson-Smith, 1973).
2. The total populations of birds are relatively small. Small populations run a higher risk of extinction, by whatever cause (MacArthur, 1973). The passenger pigeon, for instance, was reduced to a fraction of its original numbers by American settlers, and then natural population fluctuations, easily absorbed in the original stock, apparently led to extinction of the smaller flocks.
3. Bird fecundity, typically 2-3 young/breeding pair-year severely limits their ability to recoup losses to their numbers.
4. Maturation usually requires 3-4 years, delaying further the recovery process.
5. Birds often are highly aggregated, in flocks, and may expose an entire breeding population to a localized threat such as oil.
6. Some species live to 40 years or more, and many live at least a decade. If we require reestablishment of the pre-spill age distribution for recovery, we may still be waiting in 2000 A.D.

All bird species are considered as WD-NU (wide-dispersal non-ubiquitous) and recovery time is not estimated (see Section 7.3.1). WD-NU is an appropriate pigeon-hole because although any area in a denuded habitat is equally likely to be recolonized (WD), there will be a dearth of immigrants (adults and young) after a kill, and the density will be far short of the carrying capacity (NU). No recovery time is indicated because recovery time will be contingent on a number of factors about which we have little or no information. These include total population, degree of aggregation of species into discrete breeding stocks ("discrete breeding stocks" are those which would not assist each other in recovery), and extent of kill. Extent of kill in turn depends on spatial aggregation of species (what percent of population visits oiled area during period of danger), feeding techniques (diving birds are most likely to become oil-coated), and of course migratory patterns, native habitats, etc., which determine whether and when a population occurs in an area.

In short, then, a very real and serious threat to bird populations is posed by oil. Extinction is not infeasible given the proper circumstances. Wide variations in initial kill and recovery are anticipated as functions of species, season (in fact, day of year), and location of spill. (Clark (1973) reviews additional literature documenting further the threat of oil to birds).

As a next step, the previous criteria for vulnerability could be applied to Atlantic and Alaskan coast species, those most threatened identified, and simple recovery models postulated. Good fecundity and mortality data does exist for some species, and lower bounds on recovery might be generated. Lack of time has prevented pursuing such an approach during this study.

7.3.4 Recovery Model: Non-Wide-Dispersal Species

Insufficient data exist on immigration rates of Non-Wide-Dispersal (NWD) species to allow prediction of specific recovery times. Variations in recovery conditions from site to site further complicate any predictions of recovery time. Nevertheless, this class of species is reckoned the most sensitive to accidental oil spills, because of its slow dispersal strategy and uncertainties about success of the strategy. A conceptualization of recovery of an NWD species is proposed below which indicates information needs and reflects the site-specific variations in recovery time which may occur.

Recovery of NWD species is built on a two-criterion definition of recovery: both pre-spill age-distribution and density of individuals must be present for recovery to be complete. Thus, the overall recovery process can be broken down heuristically into two related processes: immigration into the decimated area, and stabilization of the colonized population. Only one of these processes is limiting to recovery in any particular case, but which one is not known in advance of the actual analysis. (If this model can be applied to a number of cases, it may be possible to ultimately discard groups of species which will be limited by one criterion.)

Any attempt to actually analyze these two coupled processes must account for several important parameters, including age-specific fecundity, mortality, and immigration rates and the areal expansion rate for the population. Immigration which is site-specific and varies from spill to spill, depends on the density of the stock population outside of the recovery zone, the size of the stock population and its distance from the recovery zone, and on the degree of obstruction by currents and landforms. Age-distribution of immigration depends on the age(s) at which the species is mobile. Areal expansion rate is also site-specific, dependent on the degree of obstruction to immigration, the speed of the mobile age(s), and the length of time per year that those age-classes are mobile. This conceptualization is based on the following assumptions:

1) Dimunition of the stock population by immigration into the recovering zone is negligible;
2) Population growth is density-independent;
3) Expansion rate is independent of un-invaded area or size of recovering population.

Since density will indeed mitigate growth when the population has reached the carrying capacity of the environment, this model gives a poor estimate of the recovery time for species in situations which reach the pre-spill density long before "equilibrium" age-distribution. These cases approach the WD-U case, and could be modeled as such if the need arises. It is thus hoped that for all NWD species the constraining factor will prove to be achievement of pre-spill density; then density-dependent effects can legitimately be neglected.

It is currently impossible to proceed with this analysis to estimate a recovery time for each species. Data on the factors which determine relevant parameters are missing for all species. Furthermore, so many of these factors are site-specific that a definitive recovery time for each NWD species cannot be determined. As the analysis is done for various cases, one may find that site-specific variations are small or are unimportant, for a species, and a single recovery time might then be surmised.

Although actual estimates of recovery time cannot yet be made for the non-wide-dispersal species, these species should nonetheless be noted as among the most sensitive at the population level to a catastrophic kill. NWD species by definition require longer than most species to reenter a decimated zone under favorable conditions. Uncertainties about unfavorable conditions surrounding particular spills increase the recovery time of these species. In lieu of a quantitative estimate of sensitivity, a qualitative statement must be made emphasizing the special sensitivity of these species to a catastrophic kill.

Table 7.3.4-1 lists the selected species from the sub-regions along the Atlantic Coast which fall into the NWD class. The species are sub-divided into the four similar groups: Spartina spp., Amphipods, Polychaetes, and Gastropods.

TABLE 7.3.4-1 Non-Wide Dispersal Species

Spartina spp.

Spartina alterniflora
Spartina patens

Amphipods

Ampelisca spp.
Corophium volutator
Orchestiidae spp.
Haustorius canadensis
Leptocheirus pinguis
Amphiporeia virginiana
Paracerceis caudata

Polychaetes

Nereis virens
Arenicola marina
Glycera dibranchiata
Clymenella torquata
Nepthys caeca
Ampharetidae spp.
Diopatra cuprea

Gastropods

Thais lapillus
Polynices duplicata
Urosalpinx cinerea
Bittium spp.

7.3.5 Recovery Model : Pelagic Species

Organisms of the pelagic zone are considered in this section. Special attention is prompted by the importance of the zone to the larval development and dispersal of most marine species, including the great majority of those exploited commercially.

The pelagic zone differs from the other habitats in defying the imposition of "boundaries" that contain a particular population. It is clear that one day a potential spill site may be swarming with juvenile shrimp, the next day infested with copepods, and so on. Because so many unpredictable variables (maybe even more so than other habitats) mediate the effect of a pelagic spill on pelagic populations, only worst case hypotheses are examined. In the process some species will still appear more or less immune to the oil threat; others receive attention compatible with the available data base.

A question arises as to what constitutes a significant loss in the pelagic biomass. If ten square miles of oceanic life is impacted and all organisms in the area killed by a spill, is that significant? What about an entire generation of copepods over Georges Bank, is that a significant loss? Rather than define significance in terms of areal, interspecies (predator-prey), or commercial effects, we simply consider impact to be significant if it would detectably (i.e., a difference could be measured with existing techniques) alter for more than a year the size or age-distribution of an impacted "breeding population". Food chain and other interspecies ramifications are not considered.

The term "breeding population" is defined by example: there is a separate breeding population (stock) associated with each of the five spawning grounds of cod indicated in Figure 7.3.5-3 and there exist separate breeding populations (stocks) of alewife, each spawning in a different native estuary, and so on. If a breeding population or portion thereof, is eliminated, somewhere in some season, a year or more later the loss will be measureable. Under this definition a population level analysis is once again warranted. Here, however, knowledge of the migratory behavior of each breeding population is necessary.

Admittedly, the analytical structure is contrived, but it is also maneageable. Especially for some fish species, "breeding populations" are identifiable, at least in a particular season. Other species, such as copepods, euphausid shrimps, cladocerans, etc., presently cannot be partitioned into breeding populations (although such assemblages may in some cases exist) and each species is treated as a single widely distributed population. Not surprisingly, in general the bigger and more diffuse the "breeding population" the smaller the potential effect of an oil spill. The importance of identifying the population unit of interest is apparent.

7.3.5.1 Analysis

Organisms of the pelagic habitat may be conveniently subdivided into planktonic species (passively drift with currents) and nektonic species (actively swim). Species which may exhibit actively controlled vertical mobility are considered as planktonic.

Plankton include phytoplankton, "resident" zooplankton or holoplankton (copepods, arrowworms, cladocerans, other minute crustacea), and "transient" zooplankton or meroplankton (the larval stages of most fish, polychaete worms, crustacea, molluscs, echinoderms, cnidarians, ctenophores, and other "lesser" phyla). Nekton includes adult fishes, squid, some shrimp, aquatic mammals, and a number of smaller species, including adult sea butterflies and jellyfish from selected species lists.

The plankton-nekton distinction proves useful in assesment of potential impact of oil occurring in the pelagic zone. This is so simply because pelagic oil takes its toll at or near the surface on organisms unable to avoid contact with a spill. Nektonic species are thus assumed essentially invulnerable to a slick. As discussed in the section on continuous spills (Section 7.6), what little is known on vertical dispersion of spilled oil suggests that potentially toxic concentrations are only found a short distance beneath the slick. In addition, it is assumed that a nektonic organism can swim away from a slick without harm. The assumption follows Nelson-Smith (1973) who hypothesizes that nektonic species avoid contaminated areas as an explanation for the apparent lack of significant fish kills following major oil spills in the pelagic zone. An alternative hypothesis (Dr. M.A. Roberts, VIMS, personal communication) is that although nekton may be most dense in the impact zone compared to other depth zones, the densities are so small as to prevent recognition of a direct kill. In such a case, avoidance is not involved. In any case, the effect is the same--little or no impact on nektonic species.

Planktonic species are not confined to surface waters and therefore are not necessarily exposed to an oil spill. However, their largely passive drifting with the currents implies the possibility of being exposed to surface conditions. Neuston--strictly surface dwelling plankton--are clearly directly threatened. However, active vertical migrators in a worst case assumption are also potentially threatened.

These points combined with the conspicuous absence of adult fish kills from even the larger offshore spills compel us to conclude that nektonic individuals probably avoid the onslaught of pelagic oil. For these reasons we restrict further attention to the fate of planktonic organisms and their respective "breeding populations".

All planktonic species (included here are species which have a planktonic stage in their life history, e.g., many fish) examined occur over a wide area or in widely separated areas; in either case a single oil slick could never pose a threat to an entire species population (except possibly birds). However, as discussed above, some species aggregate in nature into smaller breeding populations, such as the alewife native to a particular river, effectively yielding separate sub-species. If all planktonic species are sorted into the two classes--those whose members are associated with distinguishable breeding populations, and those apparently of a single, well-dispersed, region-wide stock--then a working hypothesis is that oil may pose a threat to the former class, if breeding populations are small or localized enough to be impacted by a single spill, but apparently not to the latter.

We have now deduced our way by a naive order-of-magnitude argument to a minimum set of pelagic species whose population units of interest cannot be assumed immune to oil (see Figure 7.3.5-1). Of primary interest are meroplankton, especially larvae of fish species. However, it is possible that certain holoplankton may exhibit significantly localized "breeding populations". A third group of potential interest are diving birds. However, these latter avian species have been treated in Section 7.3.4 as wide-dispersal-non-ubiquitous species. Phytoplankton, most copepods, cladocerans, and larvae of decapods molluscs, and polychaetes are assumed buffered by their areally wide distribution from the effect of a single oil spill. Undoubtedly further research may reveal breeding populations in some of these species, and a reassessment will be necessary. For the most part, however, high fecundity and/or frequent reproduction in these species should render the impact of a spill undetectable within a few weeks or months at worst. For now it appears that changes in small, localized, breeding populations are the only threat of oil in the pelagic habitat.

Data on the distribution of *Sagitta elegans* (arrowworm) states that it

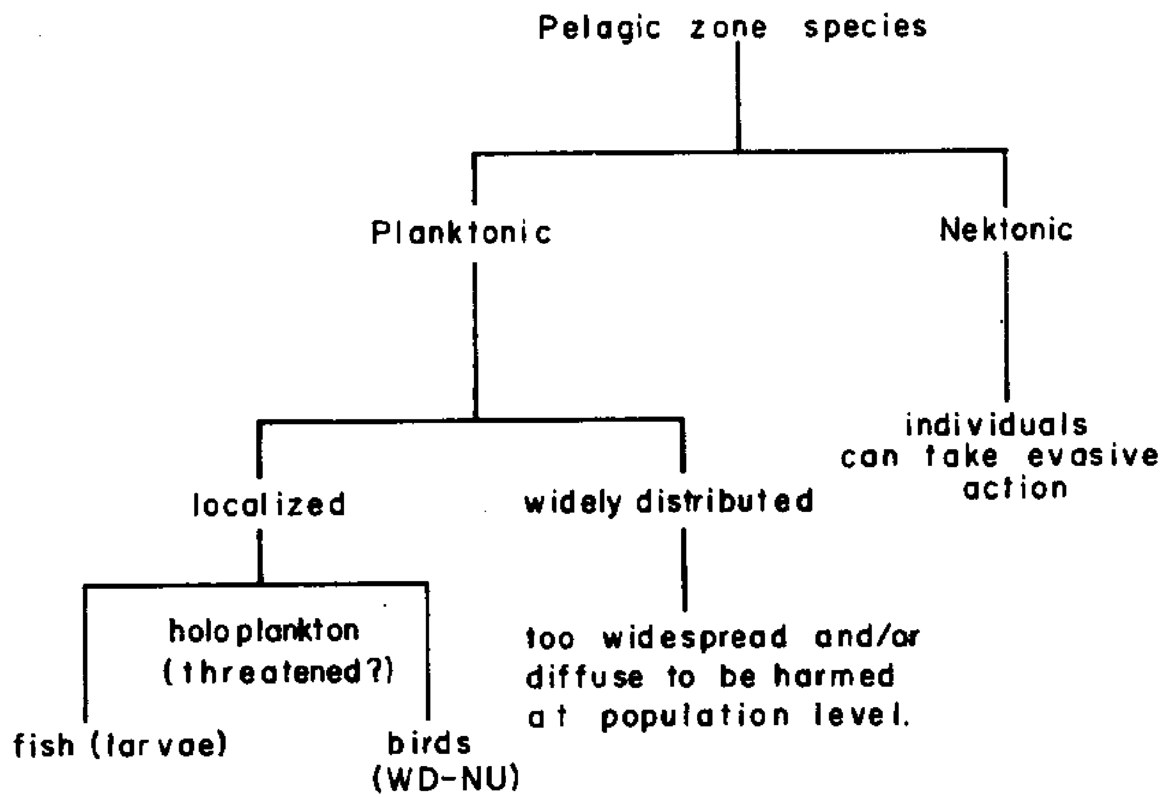

Figure 7.3.5-1. Categories of pelagic zone species for purposes of recovery analysis. See text for explanation.

is "endemic to an area," but does not indicate degree of aggregation. It is cited here as an example of holoplankton species which may be threatened in localized areas. The only pelagic species remaining to be considered are (larvae of) certain fish.

7.3.5.2 Fish and Oil

In this section the threat of oil spills to fish is discussed. This threat is via the potential effects on larval stages. For ease in analysis and reference here nearshore species from habitats other than pelagic are treated in addition to the pelagic habitat species. First, the fish and oil problem as a whole is qualitatively assessed. Second, a tentative vulnerability chart for selected fish species in each region is presented with some comment.

To the best of our knowledge and imagination there are three mechanisms by which oil may impact the individuals and thus the size and distribution of a fish population. None of the mechanisms involve mortality of adults at sea since they have been surmised to actively avoid oil-contaminated waters. This evasive response is hypothesized to occur in all species although it has been suggested for only a few.

An oil spill may lead to:

1) Egg and/or larval mortality on spawning and/or nursery grounds. Eggs and larvae may be effected by concentrations of soluble aromatic hydrocarbons in excess of .1 ppm (see Chapter 6).

2) Adult mortality or failure to reach spawning grounds if the spill occurs in a confined, narrow or shallow waterway necessary for migration or spawning. Anadromous fish crowding into an estuary would seem especially vulnerable to this hypothetical disaster.

3) Loss of a local breeding population or ability to breed due to contamination of spawning grounds, or the destruction of the nursery area by oil.

These last two possibilities have never been observed. In addition the question of fish tainting due to possible accumulation of hydrocarbons either directly from the water or through the food chain is not considered here.

Since points (2) and (3) are not explored in the literature, we can do little more than indicate when species are anadromous, spawn in shallow water, or have restricted nursery sites. The significance of a threat to any species cannot be resolved with the available data.

Degree of impact of a spill on an egg or larval cohort (individuals born in a particular year) will depend on:

(1) Time of year of spill, and season and duration of spawn. Of course the oiling must occur during or immediately preceding the spawning or larval period to present any danger. Also, however, a species with a sufficiently long spawning period could possibly sustain a spill early in the spawning season and probably still provide an adequate number of young after the oil had degraded.

(2) Aggregation of eggs and larvae. As is quite intuitive, the loss from a single spill will depend on the fraction of a population (or spawn) encountering the spill. The more aggregated the eggs or larvae, the more vulnerable the cohort and thus the population to a single spill.

(3) Type of eggs and larvae. Again, no research has been conducted on this point, but it is reasonable to expect demersal eggs and larvae to fare better than planktonic eggs and larvae when a floating oil slick invades an area. However, oil deposited in sediments may affect demersal forms.

No effort was made in this study to model fish populations mathematically and examine their response to a perturbation such as larval losses from oil. The state of the art of fisheries model often cannot account for the dynamics of fish populations (see, for example, Gulland, 1972). The controlling variables are not known. Often, recruitment is assumed constant, which of course completely obscures variability in egg and larval survival. The numbers of eggs and larvae are usually so immense that 99+% must die in the "equilibrium" population. Predation and starvation serve naturally to pare a year class down to size, but it is not clear whether initial losses by oil would be felt subsequently as a reduced number of recruits (new adults) or absorbed as a loss analagous to predation.

It is surmised here that long-lived species could probably sustain the loss of an entire year class without serious stock reduction. Short-lived species, however, such as pink salmon (a 2 year life history), subject to severe losses in a particular larval class, may suffer significant reduction in population biomass, apparently requiring a few years for recovery. This opinion certainly requires validation, but as it speaks to a very worst-case assumption--loss of entire year class--it may be somewhat reassuring for long-lived species. On the other hand, fish populations are reknowned for producing periodic dominant age classes, which can support a domestic fishery for a decade (Cushing, 1973). If such a larval class succumbs to oil (worst-case assumption), the loss would be great (although it would never be known what had been lost).

It is clear, then, that once again much more is unknown than is known. Acting on those facts available and reasonable hypotheses, vulnerability of selected fish species by region is examined below. In most cases, fish species do not appear threatened under our set of assumptions.

<u>Northern New England Region</u> (Bay of Fundy to Cape Cod) - TABLE 7.3.5-1

Seven fish species plus shrimp are included as selected species for the northern region. These include alewife, Atlantic salmon (endangered), Atlantic herring, winter flounder, cod, sand launce, mummichog, and northern shrimp (*Pandalus borealis*). Approximate breeding seasons are indicated in Figure 7.3.5-2. With suitable reservations on the two anadromous species, alewife and salmon, the possible threats from oil seemed to be to winter flounder, which has quite discrete breeding stocks and demersal eggs and larvae, the sand launce with possibly limited spawning populations and sites, and the mummichog minnow, which spawns in a few inches of water near shore.

Information was provided by the Research Institute of the Gulf of Maine (TRIGOM) on the spawning grounds of eight northern fish, and major zones of occurrence of thirty species. This information can be used to identify potentially productive fishery zones. Spawning grounds are shown in Figure 7.3.5-3, and it is interesting that only haddock, of the species shown, spawns over the proposed drilling sites. But many additional species are not dealt with in the information available for this study and some of which may of course spawn over the hypothetical drill sites.

Northern shrimp which occur predominantly in the inner Gulf of Maine appear unthreatened by oil development at the proposed sites. Inshore spills could cause some mortality, but the population seems too large and disaggregated to suffer from a single spill.

<u>Southern New England Region</u> (Cape Cod to Sandy Hook) - TABLE 7.3.5-2

Eighteen species of fish are selected for this region. These include smelt, alewife, Atlantic menhaden, scup, mackerel summer flounder, yellowtail flounder, butterfish, winter flounder, haddock, red hake, mummichog, cunner, tautog, sand launce, silversides, bluefish, striped bass, and blue-

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TABLE 7.3.5-1
FISHERIES OF NORTHERN NEW ENGLAND REGION (BAY OF FUNDY TO CAPE COD)

Species (common name)	Location of Spawning	Location of Nursery	Type of Egg/type of larva[a]	Longevity	Aggregation	Vulnerability to: offshore spill/nearshore spill[b]
Pelagic habitat selected fish species:						
Alosa pseudoharengus (alewife)	(Anadromous)	(Anadromous)	D/?	?(>9yr)	Schools at sea. Returns to native stream. Entire populations pass up often narrow streams during runs of a few weeks.	Low/(1)
Salmo salar (Atlantic salmon)	(Anadromous)	(Anadromous)	D/?	?(>4yr)	Returns to native stream.	Low/(1)
Clupea harengus (Atlantic herring)	Western coast of Gulf of Maine, Georges Bank, Nantucket Shoals	Spawning area through Dec., then offshore through winter	?/?	14(?)	Larvae aggregate during spring shoreward movement. Three parental stocks; relationship to larvae unclear.	Low/Low
Offshore bottom selected fish species (and shrimp):						
Pseudopleuronectes americanus (winter flounder)	Estuaries, bays, marshes, brackish water, Georges Bank	Brackish waters	D/D	? (perennial)	Local populations remain discrete, nonmigratory. Stays within 70 fathom contours.	Low/Moderate(?)
Gadus morhua (cod)	Eastern Georges Bank, Mass. Bay 3-10 mi. offshore, Ipswich Bay, Nantucket Shoals	Offshore. Eggs drift out of bays	P/P	9 yr	Popns. fairly discrete. Young develop offshore.	Low/Low
Pandalus borealis (shrimp)	Inshore	Inshore	?/P	?(>4)	Larvae abundant inshore in spring (through May). Adults inshore fall-spring, offshore migration with larvae in May. Wide natural fluctuations in number.	Low/Low

TABLE 7.3.5-1 (CONT'D)

Species (Common name)	Location of Spawning	Location of Nursery	Type of Egg/type of larva[a]	Longevity	Aggregation	Vulnerability to: offshore spill/nearshore spill[b]
Sand shore habitat selected fish species:						
Ammodytes americanus (sand launce)	In 5-12 fathoms of water over sandy bottom	Offshore (data for southern waters)	D/P	?(>3)	Indication of separate inshore & offshore stocks; distribution probably related to estuaries. Perhaps resort to definite spawning grounds. Larvae hatched together tend to remain together (southern waters).	Low/Low?
Salt marsh habitat selected fish species:						
Fundulus heteroclitus (mummichog)	Next to shore in a few inches of water	Marshes	?/P	?	Hugs shorelines, moving into and out of creeks to feed.	Low/Low?

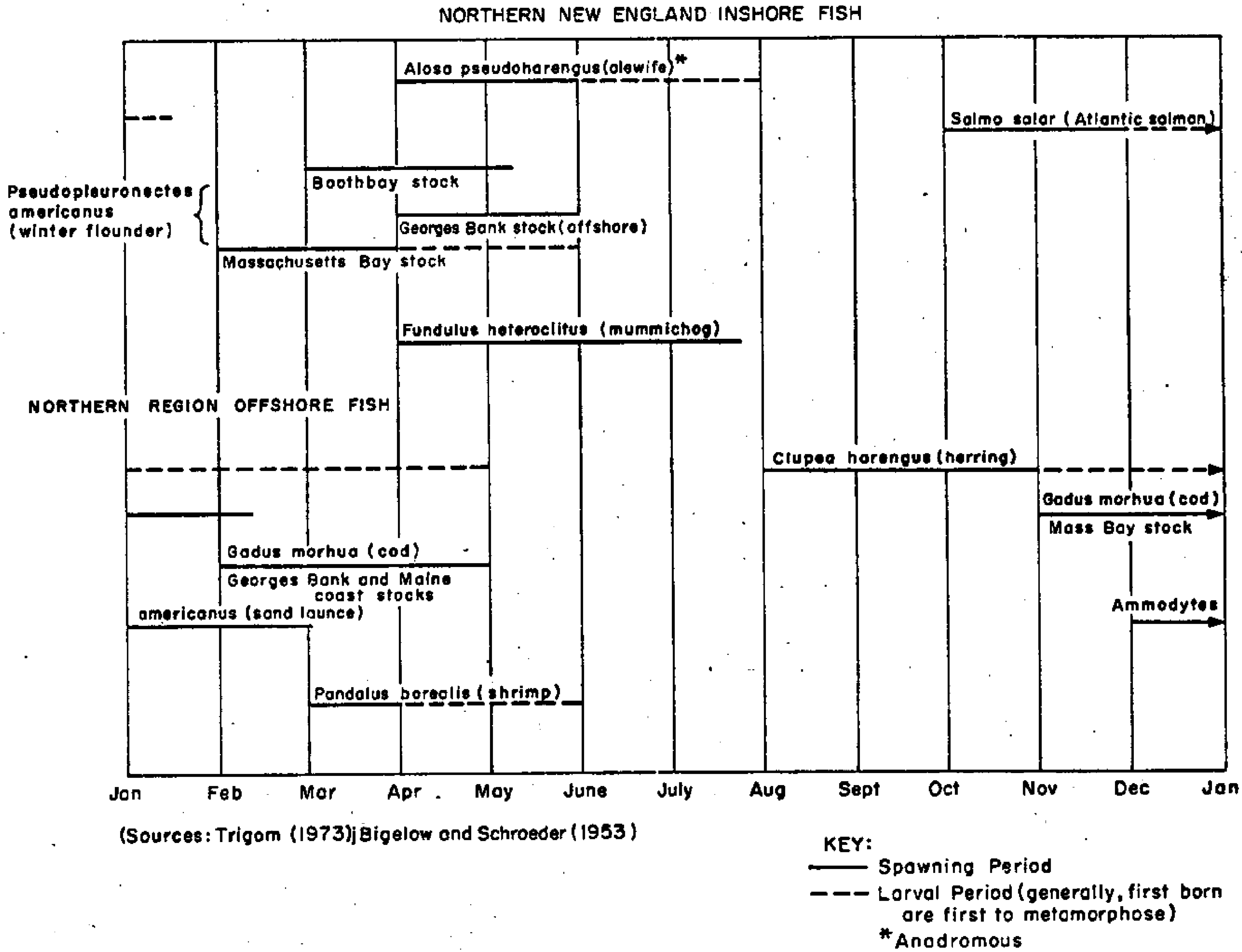
Footnotes

[a] D=Demersal
P=Pelagic

[b] (1)=some cause for concern

Figure 7.3.5-2

Period of spawning and larval development of selected fish species



(Sources: Trigom (1973); Bigelow and Schroeder (1953))

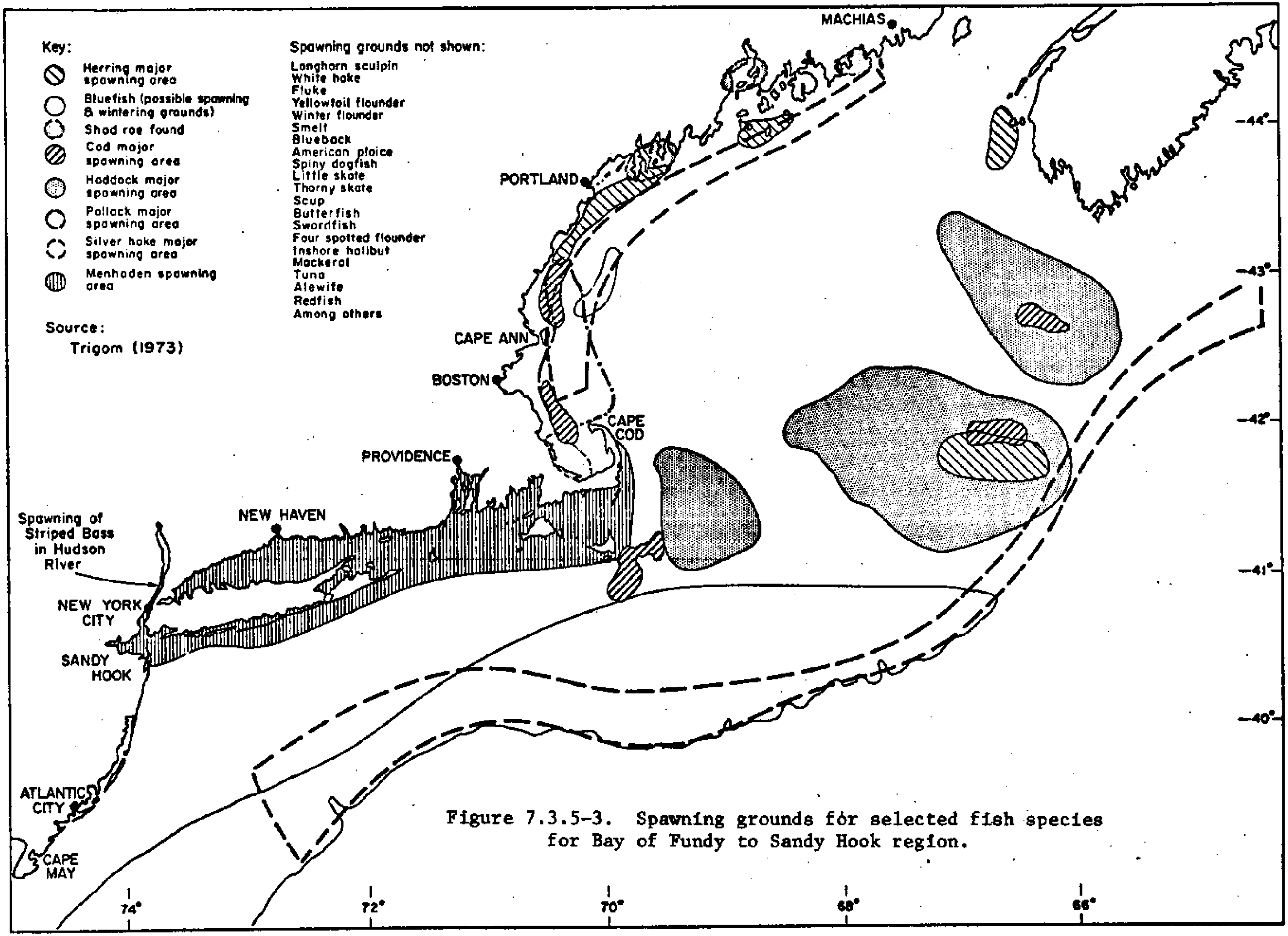


Figure 7.3.5-3. Spawning grounds for selected fish species for Bay of Fundy to Sandy Hook region.

TABLE 7.3.5-2
FISHERIES OF SOUTHERN NEW ENGLAND REGION (CAPE COD TO SANDY HOOK)

Species (common name)	Location of Spawning	Location of Nursery	Type of Egg/type of larvae[a]	Longevity	Aggregation	Vulnerability to offshore spill/nearshore spill[b]
Pelagic zone selected fish species:						
Osmerus mordax (smelt)	(Anadromous)	(Anadromous)	?/?	?(>5yr)	Schools inshore. Returns to native stream. Dense during spawning runs.	Low/(1)
Alosa pseudoharengus (alewife)	(Anadromous)	(Anadromous)	D/?	?(>9yr)	Schools at sea. Returns to native stream. Entire populations pass up often narrow streams during run of a few weeks.	Low/(1)
Brevoortia tyrannus (atlantic menhaden)	Marshes, bays, estuaries	Same	P/P	6 yr	Inshore in tight schools during warmer months. No evidence of distinct breeding populations.	Low/Low
Stenotomus chrysops (scup or porgy)	Bays, estuaries, inshore waters	Same	P/P	5 yr	Schools. No evidence of distinct breeding populations. Migrates offshore for winter.	Low/Low
Scomber scombrus (mackerel)	Inner continental shelf, primarily from south of Block Island to east of Atlantic City.	?	P/P	?(>3)	Schools. No evidence of distinct breeding populations. Extensive seasonal migrations.	Low/Low
Offshore bottom habitat selected fish species:						
Paralichthys dentatus (fluke, summer flounder)	Within 46 km. of shore	Bays and estuaries of middle Atlantic bight to Cape Hatteras. Also offshore to some extent.	P/P	?(>4)	Isolated pockets of eggs suggests existence of a number of spawning populations. Seasonal offshore migration for winter.	Low/Low?
Limanda ferruginea (yellowtail flounder)	Stationary species, 40-100 m.depth over sandy bottom	Same	P/P	7 yr ?	Discrete stocks on Georges Bank, east of Cape Cod, and south of Cape Cod, too extensive to be threatened by oil (?).	Low/Low

TABLE 7.3.5-2 (CONT'D)

Species (common name)	Location of Spawning	Location of Nursery	Type of egg/type of larvae[a]	Longevity	Aggregation	Vulnerability to offshore spill/nearshore spill[b]
Peprilus triacanthus (butterfish)	Within a few miles of shore	?	P/P	?(3)	Some schooling. Seasonal migration offshore for winter. No evidence of breeding populations.	Low/Low
Pollachius virens (pollack)	In 15-50 fathoms of water. No mention of spawning in S. New England.	Apparently inshore	P/P	10 yr. ?	Dense schools. No evidence of breeding populations.	Low/Low
Pseudopleuronectes americanus (winter flounder)	Estuaries, bays, marshes, brackish water, Georges Bank	Brackish waters	D/D	? (perennial)	Local populations remain discrete. Non-migratory. Stay within 70 fathoms depth contour.	Low/Moderate(?)
Urophysis chuss (red hake or squirrel hake)	Shoal waters (100m) along shore.	Immediate shoreline & coastal shallows (<30m)	P/P	?(>3yr)	Occur in dense, localized concentrations. Adults remain offshore in deep waters up to 1000m except to spawn.	Low/Low
Melanogrammus aeglefinus (haddock)	Georges Bank	?	P/P	14 yr.	Rarely schools. Separate spawning stocks are identifiable (GB, GM), but are probably too diffuse to suffer from single oil spill. (?)	Low/Low
Salt marsh habitat selected fish species:						
Fundulus heteroclitus (mummichog)	Next to shore, in a few inches of water	Marshes	?/P	?	Hugs shorelines, moving into and out of creeks to feed.	Low/Low ?
Rocky shore habitat selected fish species:						
Tautoglabrus adspersus (cunner)	Along rocky shores (no migration)	Same	P/P	?(>2)	Non-schooling. Abundant along rocky shores and off offshore banks. Retires to crevices or muddy area areas during dead of winter in "winter lethargy."	Low/Low

TABLE 7.3.5-2 (CONT'D)

Species (common name)	Location of Spawning	Location of Nursery	Type of Egg/type of larvae[a]	Longevity	Aggregation	Vulnerability to offshore spill/nearshore spill[b]
Tautoga onitus (tautog)	In areas of year-round occurrence (see notes under Aggregation)	Same ?	P/P	?(>4)	Non-schooling. Abundant along rocky shores, eel-grass beds, over mussel beds, among wharf pilings. Fish return to same spawning site year after year. Adults rarely journey over 5-6 mi. from coast.	Low/Low?
Sandy shore habitat selected fish species:						
Ammodytes americanus (sand launce)	Inshore and offshore, depth 15 fathoms	?	D/P	?(>3)	Indication of separate inshore & offshore groups, distribution probably related to estuaries. Diurnal vertical feeding migrations occur. Perhaps resort to definite spawning grounds. Larvae hatched together tend to remain together.	Low/Low?
Salt pond habitat selected fish species:						
Menidia menidia (silversides)	In shallow bays and marshes over sandy bottom	?	D/P	?	Form dense schools in estuaries and bays.	Low/Low
"Migratory" habitat:						
Pomatomus saltatrix (bluefish)	Offshore, 18 m. depth to edge of shelf	Inshore	P/P	?(>5) Mature between 3-5	Form tight feeding schools. Often found near concentrations of menhaden. North-South and inshore-offshore migrations are known. In this region spring and fall migrations occur.	Low/Low
Morone saxatilis (striped bass)	Anadromous, Hudson River only site of importance in region.	(Anadromous)	P/P	?(>5)	Form dense schools, even as fry. Returns to native stream. Individuals from Chesapeake also summer in this region. Rarely are striped bass found over 5 mi. from shore.	Low/(1)
Thunnus thynnus (bluefin tuna)	Mediterranean, Gulf of Mexico, Straits of Florida	Gulf Stream & Shoreward	?/P	?(>5)	Form dense feeding schools. In this region May-October. Seasonal Migration	Low/Low

<u>Footnotes</u>: [a] D=Demersal
P=Pelagic
[b] (1) some=cause for concern

fin tuna. Breeding seasons are indicated in Figure 7.3.5-4. With suitable reservations on the anadromous smelt, alewife, and striped bass, the species possibly threatened reduce to summer and winter flounder, both with possibly very discrete spawning populations, tautog, with distinct spawning populations and sites, and the sand launce, with possibly distinct spawning populations and sites. Figure 7.3.5-3 also includes spawning grounds for some of the species for this region.

Middle and Southern Atlantic Region (Sandy Hook to Cape Canaveral) - TABLE 7.3.5-3

Ten species of fish are selected for the middle and southern Atlantic region. They include hogchoker, croaker, spot, gray trout, menhaden, striped bass, spiny dogfish, scup, summer flounder, and southern kingfish. With suitable reservations on the anadromous striped bass, species possibly vulnerable to oil are hogchoker (four age-classes winter simultaneously in an estuary), and summer flounder (possibly very discrete spawning populations). Insufficient information was available to judge vulnerability of croaker, spot, gray trout, or southern kingfish. No charts of spawning or occurrence areas for southern fish species have been prepared.

Alaska Region

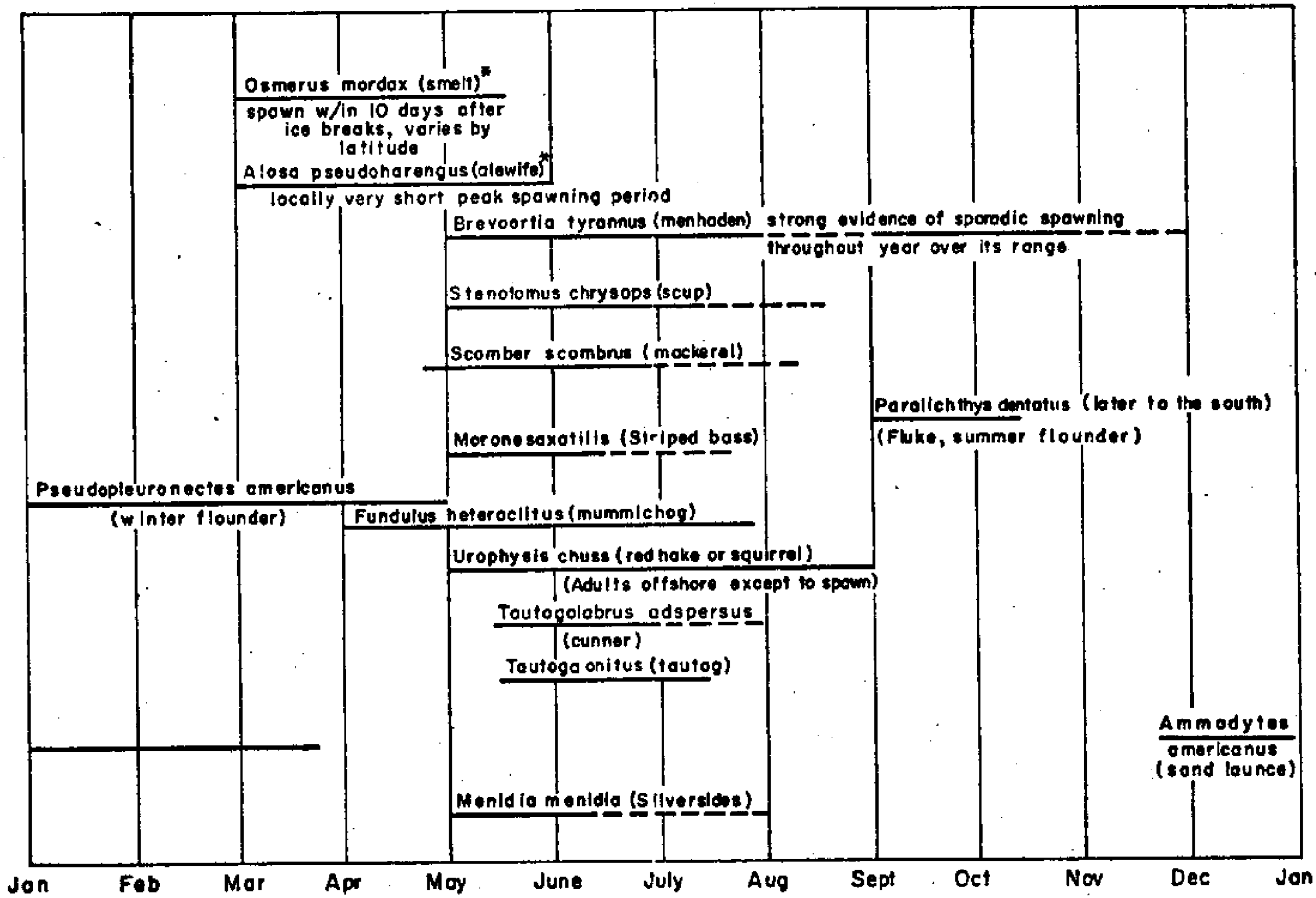
The paucity of data on fish in the Gulf of Alaska does not permit a species level analysis. It is unknown whether localized breeding populations (rendering a fish species potentially vulnerable to oil spills) occur in the offshore or coastal zones. Anadromous species of salmon are prevalent in this region. However, the degree of localization in these anadromous populations is unknown. In any case, as in Atlantic regions, few species are likely to have these sensitive characteristics, and therefore most fish species, in the Alaskan region, are not expected to be vulnerable to oil spills.

In summary, information available on the fisheries varies widely in completeness and accuracy from species to species. In addition, charts of spawning grounds and occurrence are available for only a small fraction of the species examined, and for the most part these are in the northern re-

Figure 7.3.5-4

Period of spawning and larval development of selected fish species

SOUTHERN NEW ENGLAND INSHORE FISH[1]



(Sources: Trigom (1973); Bigelow and Schroeder (1953)

KEY:

——— Spawning Period

– – – Larval Period (generally, first born are first to metamorphose)

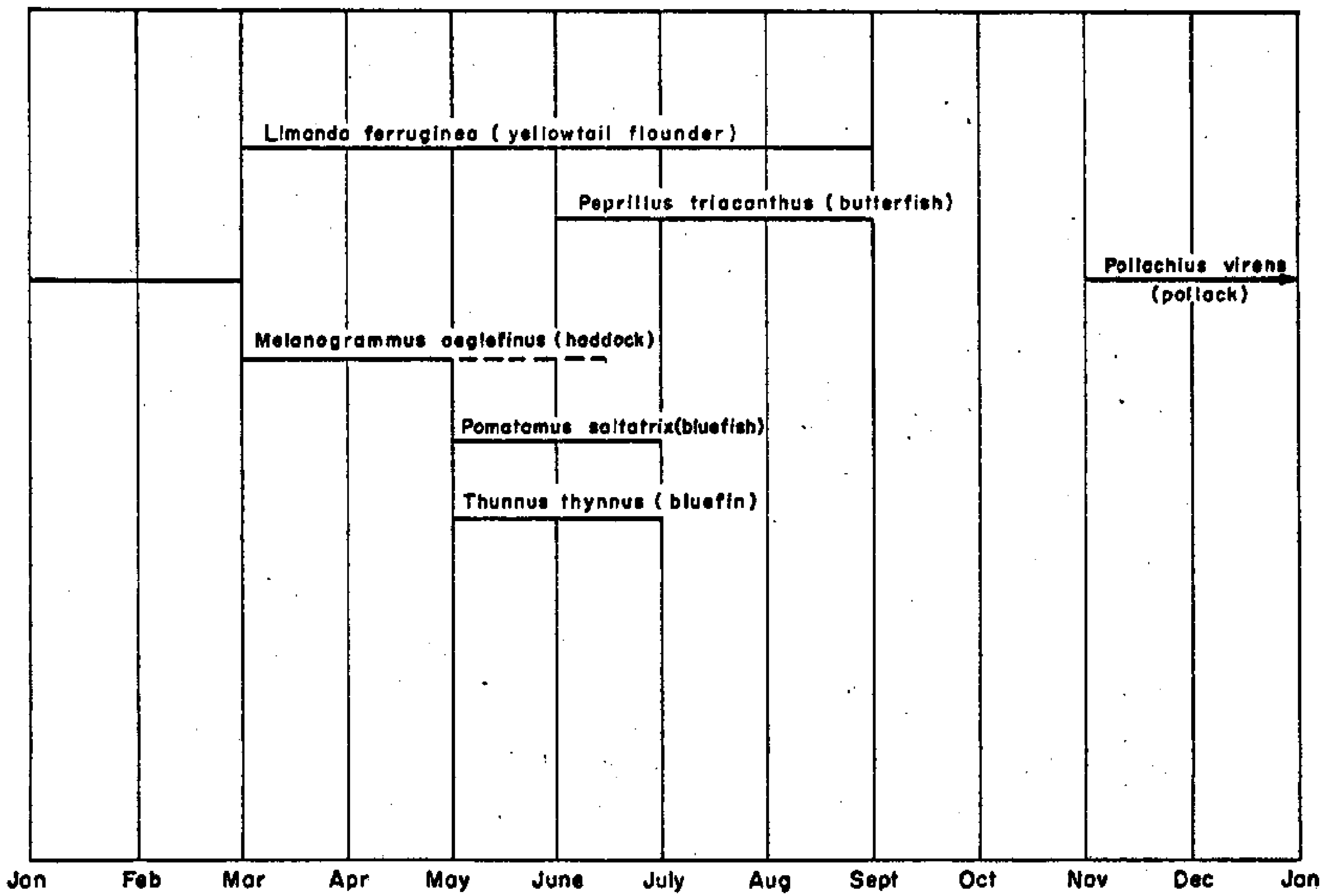
* Anadromous

1) INSHORE/OFFSHORE DISTINCTION USUALLY BY LOCATION OF NURSERY GROUNDS

Figure 7.3.5-4 (cont'd)

Period of spawning and larval development of selected fish species

SOUTHERN NEW ENGLAND OFFSHORE FISH



Sources: Trigom (1973); Bigelow and Schroeder (1953)

KEY

——— Spawning Period

– – – Larval Period (generally, first born are first to metamorphose)

* Anadromous

TABLE 7.3.5-3
FISHERIES OF SOUTHERN REGION (SANDY HOOK-CAPE CANAVERAL)

Species (common name)	Location of Spawning	Location of Nursery	Type of Egg/type of larvae[a]	Longevity	Aggregation	Vulnerability to offshore spill/nearshore spill[b]
Oligohaline system selected fish species:						
Trinectes maculatus (hogchoker)	Nearshore	Oligohaline waters and upstream	P/P?	7 yr.?	Seasonal onshore-offshore migration for 1st 4 yrs. Apparently all one- through four-year-olds congregate in low salinity zone during winter. This might be vulnerable to onshore oil spill? Maine-Panama	Low/Low?
Micropogon undulatus (croaker)	Offshore	Oligohaline waters	?/D	? (>4yr.)	No information on breeding NJ - Texas	Low/NI
Leiostomus xanthurus (spot)	Offshore	Oligohaline waters	?/?	?	Larvae & post-juveniles remain in nursery 2 yr. Mass Bay - Mexico. No info. on breeding populations.	Low/NI
Cynoscion regalis (gray trout)	Coastal	Upper estuaries	P/D	? (>5yr.)	Yearlings leave nursery. Some return to lower river following year but not afterwards. Cape Cod-Florida. No information on breeding populations.	Low/NI
Brevoortia tyrannus (menhaden)	Offshore (40 mi)	Upper estuaries	P?/P D	? (>6)	Inshore in tight schools during warmer mo. No evidence of breeding populations. Widespread, Nova Scotia - Florida.	Low/Low
Morone saxatilis (striped bass)	Anadromous	(Anadromous) (larvae only in main channels?)	D/D, then P	14 yr. (19 max.)	Exhibit dominant year classes. Extensive non-spawning migrations by northern stocks only. Each river has indigenous population. Little transfer occurs. Hudson - Mexico, esp. Cape Cod - NC.	Low/(1)

TABLE 7.3.5-3 (CONT'D)

Species (common name)	Location of Spawning	Location of Nursery	Type of Egg/type of larvae[a]	Longevity	Aggregation	Vulnerability to offshore spill/nearshore spill[b]
Medium salinity system selected fish species:						
Brevoortia tyrannus	See Oligohaline system.					
Coastal Systems fish species:						
Squalus acanthias (spiny dogfish)	Offshore	Offshore	ovovivi-parous	25-30 yr.	Low fecundity (10). Major predator of fish. Labrador - NC, especially Del. Bay & Cape Hatteras. Abundant. May overwinter inshore of 50 fm. and south of latitude 37°N.	Low/Low
Brevoortia tyrannus	See Oligohaline system.					
Stenostomus chrysops (scup)	? ("abundant in coastal & lower estuarine waters")		?/?	?(4yr)	North-south migration w/ sun. Wide fluctuations in population from year to year. Maine - SC, esp. NJ Maryland, Virginia, NC.	Low/Low
Paralichthys spp. (summer flounder)	Within 46 km of shore	Bays & estuaries middle of Atlantic Bight south to Cape Hatteras. Also offshore to some extent.	P/P	?(4yr)	Inshore in summer, offshore in fall. Isolated pockets of eggs suggest existence of breeding populations. Mass.-Fla.	Low/Low?
Menticirrhus americanus (southern kingfish)	Nearshore waters, bay mouths	Offshore ?	?/?	?	No information	Low/NI

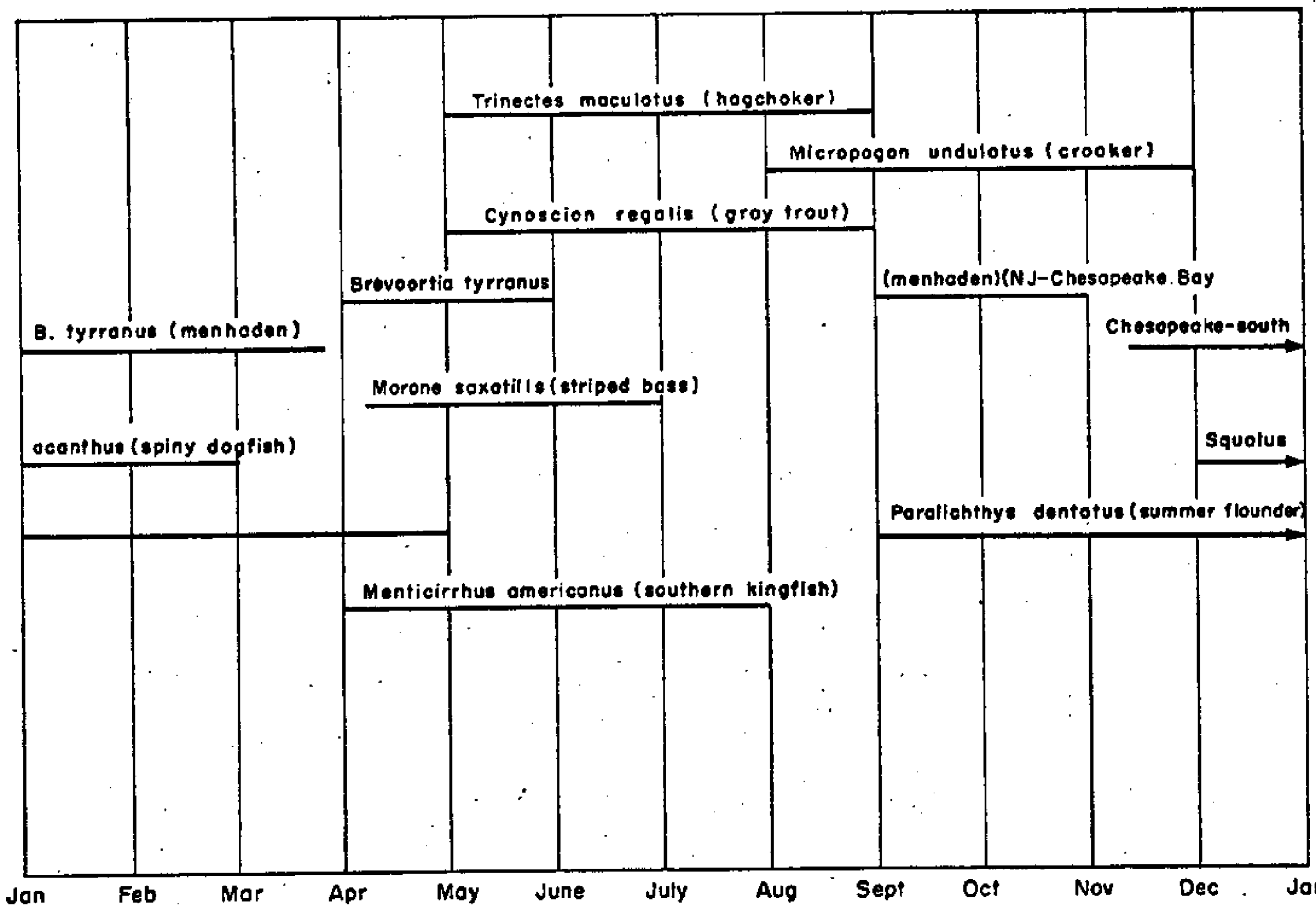
Footnotes

[a]D=Demersal
P=Pelagic

[b](1) some=cause for concern

Figure 7.3.5-5

Period of spawning and larval development of selected fish species
SOUTHERN ATLANTIC INSHORE FISH



Sources: VIMS (1973)

KEY:
—— Spawning Period
– – – Larval Period (generally, first born are first to metamorphose)
* Anadromous

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gion. The choice of species discussed in the report was made by different individual subcontractors (TRIGOM, URI, VIMS) who placed different emphasis on the importance of fish in their choice of selected species. This is illustrated by the total number of fish in the selected species lists for each region: 7 (North New England), 19 (Southern New England), 10 (Middle and Southern Atlantic). Selecting a fish species in a region does not reflect a relatively high occurrence of the fish in that region. In fact, many of the middle region species are actually centered in the Gulf of Maine, or off North Carolina, etc., yet were not chosen as selected species by the other regional contractors. These discrepancies are a product of the time schedule of this project, precluding closer coordination of the various regional studies, and of the differing interest and expertise of the contractors. Realizing this, <u>one cannot differentiate the sensitivities of the three regional fisheries from the conclusions of this fisheries section</u>.

7.4 Accidental Spill Model : Regional Habitat Analysis

Sections 7.2 and 7.3 provide a population level analysis of impact and recovery of oil spills without reference to specific marine habitats (except the pelagic zone in Section 7.3.5). In this section the approach developed is applied to the species selected for each habitat in each of the three Atlantic regions (see Chapter 4).

The results presented below are for the worst-case condition of 100% mortality to a population in a habitat. The results are not of actual spill impacts, but rather provide a basis when combined with Chapter 5 for estimating a general "habitat vulnerability".

7.4.1 Recovery-Time Estimates for Selected Species

Tables 7.4-1 to 7.4-23 list by species approximate time to recovery for a population decimated by oil, excluding the lapse until the substrate becomes suitable. For WD-U species, it is argued (Section 7.3.2) that recovery time is of the order of longevity. Certainly if replacement of elder individuals is held a partial criterion for recovery, then longevity provides a lower bound on recovery time. For WD-NU species, such as birds (Section 7.3.3), recovery is not predicted and ** is entered in the tables

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TABLE 7.4-1

HABITAT SELECTED SPECIES
RECOVERY ANALYSIS

Bay of Fundy - Cape Cod:
Pelagic Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Thalassiosira ssp. *Chaetoceros* spp. *Ceratim* spp. (phytoplankton)	Pelagic	(Sub) annual	Few days - few weeks		Dominant phytoplankton during the spring and summer blooms. Basis of the food chain.
Calanus firmarchicus *Pseudocalanus minutus* *Orthona similis* *Microsetella norvegica* *Acartia* ssp. *Eucheata norvegica* *Tortanus discaudatus* (copepods)	Pelagic	(Sub) annual	Few months - 1 year	Typically several generations per year.	Dominant herbivores; main food source for higher consumers.
Limacina retroversa (sea butterfly)	Pelagic	(Sub) annual	Few months - 1 year	Primarily nektonic. All may exhibit localized concentrations.	?
Evadne nordmanni (cladoceran)					
Sagitta elegans (arrowworm)					
Meganyctiphanes norvegica (euphausid)					
Aurelia aurita (jelly fish)					
Pleurobrachia pileus (comb jelly)					
Polychaete, mollusca, decapod larvae					
Fish larvae	Discussed by species in text (Section 7.3.5.2)				
Rissa tridactyla (kittiwake)	WD-NU	? 4 years	**	No localization of nesting, wintering, etc.	?
Dovekie	WD-NU	2 years	**	Very dense population migrate together.	?
Fish species: *Salmo salar* (salmon), *Clupea harengus* (herring)					

TABLE 7.4-2

Bay of Fundy - Cape Cod:
Offshore Bottom Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Nepthys incisa (polychaete worm)	WD-U	(Perennial) (?)	?		Errant; predatory and deposit feeder.
Nucula proxima (bivalve)	NWD	12 - 20 years	*	Broods young. Limited dispersal by short-lived larval stage. Extent of adult mobility unclear.	Deposit feeder.
Ampelisca vadorum (amphipod)	NWD	(Sub) annual	*	Two generations per year. Recovering slowly at West Falmouth, Mass.	?
Ophiura robusta (brittel star)	WD-U	10 - 15 years	15 years		Deposit feeder.
Arctica islandica (mahogany quahog)	WD-U	10 years (?)	10 years (?)	Sand and sandy mud bottoms.	Filter feeder.
Spisula solidissima (surf clam)	WD-U	17 years (maximum)	17 years	Commercial species.	Filter feeder.
Placopecten magellanicus (scallop)	WD-U	9 years (?)	10 years (?)	Slight mobility.	Filter feeder.
Fish species: *Gadus morhua* (cod), *Pseudopleuronectes americanus* (winter flounder), *Pandalus borealis* (northern shrimp)					

TABLE 7.4-3

Bay of Fundy - Cape Cod:
Rocky Shore Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Ascophyllum nodosum (rock weed)	WD-U	8 years (average) - 15 years (maximum)	8 years	Regenerates if not severed below region of active growth (at least 5-25 cm). Young plants very sensitive. Denuded areas very slow to re-establish.	Competitor fucoids are more prolific and can repopulate denuded areas faster.
Laminaria spp. (Kelps)	WD-U	1-2 years	2 years (if kill occurs)	Relatively resistant to oil. Fronds are annual, but some hold-fasts survive and plant is perennial.	Recovery can be seriously impared by sea urchin grazing of shoots.
Balanus balanoides (barnacle)	WD-U	3 years	3-5 years	Release of "hatching substance" triggers release of nauplii.	A filter feeder.
Littorina littorea (periwinkle)	WD-U	2 years	2 years (if kill occurs)	Relatively resistant to effects of oil.	Browser.
Metridium dianthus (sea anemone)	WD-U	?	?	Adults show little mobility, live in clusters.	?
Thais lapillus (dog whelk)	NWD	7 years (maximum)	* (if kill occurs)	Quite resistant to effects of oil. Age of first spawning--2.5-3 years.	Important predator on barnacles.
Strongylocentrotus droebachiensis (sea urchin)	WD-U (?)	4 years	4 years	Larval stage 2-3 months.	?
Mytilis edulis (blue mussel)	WD-U	4 years (7 years maximum)	4 years	May become tainted. Commercial species.	A filter feeder.
Homarus americanus (lobster)	WD-U	10+ years	?	Significant adult immigration possible, making estimate of recovery virtually impossible; effects of oil spill <u>may</u> be detectable after one year.	A scavenger.
Eider duck	WD-NU	?	**	Two populations on Maine coast. Small population winters there and breeds locally.	May transmit a parasite (via faeces) to mussels, causing "pearls".

TABLE 7.4-4

Bay of Fundy - Cape Cod:
Sand Shore Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Tellina agilis (bivalve)	WD-U (?)	10+ years	10 years		Filter feeder. A major fish food.
Pagurus longicarpus (hermit crab)	WD-U	(Perennial) ?	?		Scavenger
Nephtys caeca (polychaete worm)	?	?	?		Member of *T. agilis* community and *M. mercenaria* community. Errant deposit feeder.
Haustorius canadensis (amphipod)	NWD	Annual	*	Lives near surface at low tide.	?
Echinarachnius parma (sand dollar)	WD-U	(Perennial) ?	?		Detrital feeder.
Spisula solidissima (surf clam)	WD-U	17 years (maximum)	17 years	Inhabits sandy sediments nearshore and offshore. Commercial species.	Filter feeder.
Fish species: *Ammodytes americanus* (sand launce)					

TABLE 7.4-5

Bay of Fundy - Cape Cod:
Worm and Clam Flat Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Mya arenaria (soft-shell clam)	WD-U	7 years	7 years	Older ages are commercially important. May become tainted.	Filter feeder.
Mercenaria mercenaria (quahog or hard clam)	WD-U	6+ years	6 years	Older clams subject to "catastrophic" mortality from severe winter conditions. Tainting possible. Commercially important.	Filter feeder. Young heavily preyed upon by crabs.
Nereis virens (sand worm)	WD-U	4 years	4 years	Sexual maturity at 3 years old. Feeding likely triggered by chemical cues.	Predatory and deposit feeder.
Arenicola marina (lug worm)	WD-U	2+ years	2+ years	Very brief (24 hours) larval swimming stage; sexual maturity at 2 years.	Indirect deposit feeder.
Streblospio benedicti (polychaete worm)	WD-U	Annual	1 year		?
Corophium volutator (amphipod)	NWD	(Sub) annual	*	A related amphipod is recovering slowly at West Falmouth, Mass.	?
Nassarius obsoletus (snail)	WD-U	3+ years	3+ years	Highly developed response to chemical cues has been shown.	?
Limulus polyphemus (horseshoe crab)	WD-U	14-19 years	15 years		?
Glycera dibranchiata (bloodworm)	WD-U	5 years	5 years	1 day pelagic stage for larvae; 3+ year olds are chief spawners.	Deposit feeder.
Macoma balthica (bivalve)	NWD	2+ years	*	High mortalities after 2 years.	Deposit feeder.
Crangon septemspinosus (shrimp)	WD-U	Disputed; 1-3 years	1-3 years	Autumn offshore migration by juveniles.	?

TABLE 7.4-6

Bay of Fundy - Cape Cod:
Mussel Reef Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Crassostrea virginica (Virginia oyster)	WD-U	4-6 years	4-6 years	Valuable commercial species. Estuarine.	Filter feeder.
Crepidula fornicata (slipper shell)	WD-NU (?)	? (Perennial)	?	Occur in colonies. Aggregation may be chemically mediated.	?
Harmothoe imbricata *H. extenuata* (polychaete worms)	WD-U (?)	?	?	Very common on shell, gravel, or rocks. Probably attracted to host chemically.	Often lives in tubes or borrows of other invertebrates.
Asterias vulgaris *A. forbesi* (starfish)	WD-U	? (perennial)	?	Sensitive to toxic chemicals; will not cross substrate treated with them.	Predator on bivalves.

TABLE 7.4-7

Bay of Fundy - Cape Cod:
Salt Marsh Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Spartina alterniflora (cordgrass)	NWD	Annual shoots; perennial rhizomes.	* (Depends on whether or not rhizomes are killed.)	Spreads by seed and underground shoot, with local expansion primarily by shoots.	Very important source of organic detritus; indispensable in energy flow pattern of inshore waters. Also provides habitat prerequisite to occurrence of the following species.
Clymenella torquata (bamboo worm)	NWD	* (Perennial)	*	Demersal eggs and larvae; tubiculous adult.	?
Orchestiidae (amphipods)	NWD	Annual	*	Other amphipods (*Ampelisca*) are recovering very slowly at West Falmouth.	Detrital feeder. Lives under moist seaweed between high and low water.
Dipterous larvae (fly larvae)	WD-U	Annual		If a year class perishes, other flies from another marsh will locate and lay eggs in the impacted marsh.	?
Crangon septemspinosus (shrimp)	WD-U	Disputed (1-3 years)	1-3 years	Autumn offshore migration by juveniles.	?
Ammospiza lecontei (sharptailed sparrow)	WD-NU	?	**	Breeds from Massachusetts southward along coast. Resident in Mass., May-September.	?
Melampus bidentatus (pulmonate snail)	?	?	?		?
Fish species: *Fundulus heteroclitus* (mummichog), *Pseudopleuronectes americanus* (winter flounder)					

TABLE 7.4-8 and 9

Cape Cod - Sandy Hook:
Pelagic Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Branta bernicla (brant)	WD-NU	? (3 year)	**	Nests in Arctic, winters in coastal area, Cape Cod to North Carolina.	?
Pelecanus occidentalis (brown pelican)	WD-NU	? (Perennial)	**	Endangered Species. A southern region species (N.C. - Fla.) with rare sightings in this region and declining numbers in the south.	?
Oceanites oceanicus (Wilson's petrel)	WD-NU	?	**	Nests in Antarctica (Dec. - Feb.); off N. Atlantic coast May - September. Rests at night on sea surface.	?
Skeletonema costatum *Thallasiosira* spp. *Chaetoceros* spp. *Leptocylindris* spp. *Nitzchia* spp. (phytoplankton)	Pelagic	(Sub) annual	A few weeks at most.		The dominant phytoplankton during the spring and summer blooms. Primary producers--basis of pelagic food chain.
Acartia spp. *Calanus* spp. *Oithona* spp. *Centropages* spp. *Pseudocalanus minutus* (copepods)	Pelagic	(Sub) annual	A few months at most.	Typically reproduce three to four times per year.	The dominant herbivores; main food source for higher consumers.
Sagitta elegans (arrowworm)	Pelagic	(Sub) annual	A few months at most.	Endemic to localities, but too dispersed to be seriously threatened by a spill. Four spawning seasons per year.	?
Balaenoptera musculus (blue whale)	WD-NU	20-40 + years	**	Endangered Species. Not individually vulnerable to oil spills.	Graze tons of zooplankton for food.
Balaena glacialis (right whale)	WD-NU	?	**	Endangered Species. Not individually vulnerable to oil spills.	?
Megaptera novaeangliae (humpback whale)	WD-NU	?	**	Endangered Species. Not individually vulnerable to oil spills.	?
Balaenoptera physalus (fin whale)	WD-NU	?	**	Endangered Species. Not individually vulnerable to oil spills.	?

Fish species: *Osmerus mordax* (smelt), *Alosa pseudoharengus* (alewife), *Brevoortia tyrannus* (Atlantic menhoden), *Stenotomus chrysops* (scup or porgy), *Scomber scombrus* (mackerel).

TABLE 7.4-10

Cape Cod - Sandy Hook:
Offshore Bottom Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comment	Relevant Interspecies Effects
Nucula spp. (bivalve)	NWD	12-20 years	*	Extent of adult mobility unclear. Broods its young. Limited dispersal by short-lived largal stage.	A deposit feeder.
Tellina agilis (bivalve)	WD-U (?)	10 + years	10 years		A filter feeder. Food for fish.
Cancer spp. (rock and Jonah crabs)	WD-U	? (Perennial)	?	Onshore - offshore migrations. Possible chemical interference by oil with mating behavior.	A scavenger.
Pherusa affinis (polychaete worm)	WD-?	?	?		Very significant food for winter flounder. A deposit feeder.
Ceriantheopsis americanus (anthozoan)	WD-?	"Many years"	"Many years"	Occupies a permanent burrow in silt and silty sand.	A suspension feeder.
Nepthys incisa (polychaete worm)	WD-U	? (Perennial)	?		Errant; predatory and deposit feeder.
Ampelisca vadorum (amphipod)	NWD	(Sub)annual	*	Two generations per year. Recovering slowly at W. Falmouth, Mass.	?
Leptocneirus pingue (amphipod)	?	?	?		Important fish food.
Ampharetid spp. (polychaete worms)	?	?	?		?

TABLE 7.4-11

Cape Cod - Sandy Hook:
Rocky Shore Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Fucus spp. (rockweed)	WD-U	?	?	Aggressive colonizer.	Creates a microhabitat supporting numerous species.
Ascophyllum nodosum (rockweed)	WD-U	8 year (average) - 15 year (maximum)	8 years	Regenerates if not severed below region of active growth. Young plants very sensitive. Denuded areas slow to reestablish.	Competitor fucoids are more prolific and can repopulate a denuded area.
Laminaria spp. (kelp)	WD-U	1-2 years	2 years	Relatively resistant to effects of oil. Fronds are annual, but some holdfasts survive and plant is perennial.	Recovery can be seriously impared by sea urchin grazing of shoots.
Balanus balanoides (barnacle)	WD-U	3 years	3-5 years	Release of "hatching substance" triggers release of nauplii.	A filter feeder.
Mytilis edulis (blue mussel)	WD-U	4 years (7 yrs. max.)	4 years	May become tainted. Commercial species.	A filter feeder.
Littorina littorea (periwinkle)	WD-U	2 years	2 years	Relatively resistant to effects of oil.	A browser.
Thais lapillus (dog whelk)	NWD	7 years (maximum)	* (if kill occurs)	Quite resistant to effects of oil. Age of first spawning: 2.5 - 3 years.	Important predator on barnacles.
Asterias forbesi (star fish)	WD-U	? (Perennial)	?	Adult migration foils prediction of recovery time. Sensitive to toxic chemicals.	Important predator on mussels and oysters.
Homarus americanus (lobster)	WD-U	10 + years	?	Significant adult immigration possible, making estimate of recovery time virtually impossible; effects of a spill <u>may</u> be undetectable after one year.	A scavenger.
Cancer borealis (Jonah crab)	WD-U	? (Perennial)	?	During winter, major population moves offshore and individuals dig into sand emerging occasionally to feed. Oil may interfere with chemically cued mating behavior.	A scavenger.
Arbacia punctulata (sea urchin)	WD-U	4-8 years	4-8 years		?

(continued)

Table 7.4-11, continued

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Larus argentatus (herring gull)	WD-U	4-8 years (average) 30 years (maximum)	**	Nests along Atlantic south to Long Island. Migrates south (August to November) along entire coastline.	?
Halichoerus grypus (gray seal)	WD-NU	25-35 years	** (Decades, if kill occurs)	Cows mature at age 5, bulls at 6. Typical densities <u>very</u> low.	

TABLE 7.4 - 12

Cape Cod - Sandy Hook:
Sandy Shores Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Tellina agilis (bivalve)	WD-U (?)	10 + years	10 years		A filter feeder. A major fish food.
Spisula solidissima (surf clam)	WD-U	17 years (maximum)	17 years	In this region, the densest beds are off southeastern Long Island. Commercially important.	A filter feeder.
Pagurus longicarpus (hermit crab)	WD-U	?	?		A scavenger.
Haustorius canadensis (amphipod)	NWD	Annual	*	Lives near surface at high tide.	?
Nepthys caeca (polychaete worm)	?	?	?	Member of *T. agilis* community and *M. mercenaria* community.	Errant deposit feeder.
Echinarachnius parma (sand dollar)	WD-U	? (Perennial)	?		A detrital feeder.
Emerita talpoida (sandmole crab)	WD-U	1-2 years	1-2 years	Adults congregate; mechanism unknown. In northern range, winters over in 6 to 12 feet of water. Digs temporary burrows in sand.	Filters food from receding waves.
Polynices duplicata (predatory snail)	?	?	?		Preys on bivalves by drilling shells.
Sterna hirundo (common tern)	WD-NU	25-30 years (maximum)	**	Breeds on sandy beaches and small islands from Newfoundland to North Carolina. First mating, age 2-3. Winter migration to (especially) eastern South America.	?
Numenius borealis (Eskimo curlew)	WD-NU	Approximately 30 yrs. (maximum)	**	Near Extinction. Formerly an abundant southern migrant over L.I. Nested in N.W. Canada and along arctic coast. Recent rare sightings in Texas.	
Passerculus princeps (Ipswich sparrow)	WD-NU	5-9 years	**	Rare. Breeds only on Sable Island, Nova Scotia. Winters on coastal dunes, Massachusetts to Georgia.	?
Halichoerus grypus (grey seal)	WD-NU	25-35 years	** (Decades, if kill occurs)	Cows mature at age 5, bulls at age 6. Typical densities very low.	?
Fish species: *Ammodytes americanus* (sand launce)					

TABLE 7.4-13

Cape Cod - Sandy Hook:
Salt Marsh Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Spartina alterniflora (cordgrass)	NWD	Annual shoots; perennial rhizomes.	* (Depends on whether or not rhizomes are killed.)	Spreads by seed and underground shoot with local expansion primarily by shoots.	Very important source of organic detritus; indispensable in energy flow pattern of inshore waters. Provides habitat prerequisite to occurrence of many species.
Modiolus demissus (ribbed mussel)	WD-U	? (Perennial)	?	May become tainted. Occurs in clumps at roots of *Spartina*. Sessile.	A filter feeder. A major food for birds and mammals. Young are predation limited; adults are competition limited.
Littorina littorea (periwinkle)	WD-U	2 years	2 years (if spill occurs)	Relatively resistant to effects of oil spill.	A browser.
Melampus bidentatus (pulmonate snail)	?	?	?		?
Carcinus maenas (green crab)	WD-U	3 years (average) - 6 years (maximum)	3 years	No evidence of chemical cues for mating.	Major predator on bivalves.
Uca spp. *U. pugnax* *U. pugilator* *U. minax* (fiddler crabs)	WD-U	<2 years	2 years	Chemical cues very important to mating and feeding. Found in wet muddy substrate. Found in sandy substrate. Found in brackish upper marsh.	Scavengers.
Agelaius phoeniceus phoeniceus (eastern red-winged blackbird)	WD-NU	4-7 years	**	Nests in cattails, rushes, marshgrass, salt and fresh water marshes, Nova Scotia to Florida. Winters from Massachusetts to Florida. Migrates inland through coastal states.	?
Pandion haliaetus (osprey)	WD-NU	21 years (maximum)	**	Possibly rare. Nests in tree tops but mostly near water, in fresh and salt ponds, and marshes. Newfoundland to Florida. Diving bird.	Migration timed to shad and herring runs

(continued)

Table 7.4-13, continued

Cape Cod - Sandy Hook:
Salt Marsh Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Ondatra zibethica (muskrat)	WD-NU	21 years (maximum)	**	Constructs mound house of sticks, mud, and leaves with underwater entrances. No data exists on individual response to oil (avoidance is possible). Seasonal movements occur (not migrations). Wide fluctuations in population are normal.	?
Microtus pennsylvanicus provectus (Block Island meadow vole)	NWD	1-1/2 to 3 years	Recovery in 1-2 years if adequate local survivors. Otherwise unpredictable.	Rare, endemic to Block Island. Up to 17 litters of 1-9 young per year. Wide population fluctuations every 3 - 4 years.	?
Orchestia palustris (amphipod)	NWD	Annual	*	Other amphipods (*Ampelisca*) recovering very slowly in West Falmouth. Lives under moist seaweed between low and high water.	A detrital feeder.
Anas rubripes (black duck)	WD-NU	16-20 years (maximum)	**	Winters along Atlantic coast: Quebec to Florida.	?
Melanitta deglandi (white-winged scoter)	WD-NU	?	**	Nests in central and western Canada. Summers: south to Massachusetts. Winters: New Brunswick to South Carolina along the coast.	?
Larus argentatus (herring gull)	WD-NU	4-8 years (average) 30 years (maximum)	**	Nests along Atlantic south to Long Island. Migrates south (August to November) along entire U.S. coastline.	?
Fish species: *Pseudopleuronectes americanus* (winter flounder), *Menidia menidia* (silversides)					

TABLE 7.4-14

Cape Cod - Sandy Hook:
Salt Pond Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Interspecies Effects
Zostera marina (eelgrass)	NWD	Vertical shoots annual; rhizomes are perennial.	* (Depends on whether rhizomes are killed or not.)	Contributes about 1/6 of all plant debris. Grows only in still water. *Zostera* required over 40 years to recover from an epidemic which struck in the 1930's.	Provides habitat for bay scallop, other species. Provides a substrate for epiphytic species. Reduces current action.
Ruppia maritima (aquatic angiosperm)	?	?	?		?
Ulva lactuca (sea lettuce)	WD-U	?	?		?
Skeletonema costatum	(See Pelagic Habitat)				
Chaetoceros spp.	(See Pelagic Habitat)				
Acartia clausi	(See Pelagic Habitat)				
Acartia tonsa	(See Pelagic Habitat)				
Nereis virens (sand worm)	WD-U	4 years	4 years	Sexual maturity at 3 years. Feeding likely triggered by chemical cues.	Predatory and deposit feeder. Errant.
Gemma gemma (bivalve)	NWD	2 years	*	Very high natural mortality. No larval stage, all dispersal of juveniles by wave or current action. Most settling occurs immediately around release site.	?
Crassostrea virginica (Virginia oyster)	WD-U	4-6 years	4-6 years	Recovery at West Falmouth very slow. Valuable commercial species. Estuarine.	Filter feeder. Preyed on by boring snails and sponges.
Mercenaria mercenaria (quahog or hard clam)	WD-U	6 + years	6 years	Tainting possible. Older clams subject to "catastrophic" mortality from severe winter conditions. Commercially important species.	Young preyed upon heavily by crabs. Filter feeder.
Spisula solidissima (surf clam)	WD-U	17 years	17 years	In this region, heaviest concentration off southeastern Long Island. Commercially important species.	Filter feeder.

(continued)

Cape Cod - Sandy Hook:
Salt Pond Habitat

Table 7.4-14, continued

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Mya arenaria (soft shell clam)	WD-U	7 years	7 years	Older ages are commercially important. May become tainted.	Filter feeder.
Nassarius obsoletus (mud snail)	WD-U	? (3 + years)	3 + years	Highly developed response to chemical cues has been shown.	
Pagurus longicarpus (hermit crab)	WD-U	? (Perennial)	?		Scavenger.
Callinectes sapidus (blue crab)	WD-U	3.5 years	3.5 years	Migratory. Commercially important.	Predatory.
Aytnya marila (greater scaup)	WD-NU	?	**	Nests in Alaska and northwestern Canada.	?
Anas rubripes (black duck)	WD-NU	16-20 years (maximum)	**	Winters along Atlantic coast, Quebec to Florida. Nests in trees and on ground near fresh and salt ponds, marshes, and swamps. Breeds: Newfoundland - Virginia. Winters: from New Brunswick southward.	?
Melanitta deglandi (white-winged scoter)	WD-NU	?	**	Nests in central and western Canada. Summers: south to Massachusetts (?). Winters: Gulf of St. Lawrence to South Carolina along coast..	?
Pandion haliaetus (osprey)	WD-NU	21 years (maximum)	**	Possibly rare. Diving bird. Nests in tree tops, but mostly near water; in fresh and salt ponds and marshes. Newfoundland to Florida.	?
Larus argentatus (herring gull)	WD-NU	4-8 years (average) 30 years (maximum)	**	Nests along the Atlantic south to Long Island. Migrates south (August to November) along entire U.S. coastline.	?
Fish species: *Menidia menidia* (silversides)					

TABLE 7.4-15

Cape Cod - Sandy Hook:
Worm and Clam Flats Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Mercenaria mercenaria (quahog or hard clam)	WD-U	6 + years	6 years	Commercially important. May become tainted. Older clams subject to "catastrophic" mortality from severe winter conditions.	Filter feeder. Young preyed upon by crabs.
Ensis directus (razor clam)	WD-U	? (Perennial)	?		?
Pectinaria gouldii (trumpet worm)	WD-U (?)	3 years	3 years	Tubiculous.	?
Clymenella torquata (bamboo worm)	NWD	? (Perennial)	*	Demersal eggs and larvae; tubiculous adult.	?

TABLE 7.4-16

Sandy Hook - Cape Canaveral:
High Energy Beach Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Donax variabilis (Coquina clam)	WD-U	Annual	1 year	Pronounced annual fluctuations. *Donax* spp. occur from Long Island to Florida.	Preyed upon by birds, fish, crabs, snails. Filters receding water of breaking waves.
Emerita talpoida (sand mole crab)	WD-U	1-2 years	1-2 years	Digs temporary burrows in the sand. Migrates up and down beach with tide. In northern range, winters over in 6'-12' water. In southern range remains intertidal. Forms aggregations Massachusetts to Florida.	Filter feeder.
Calidris alba (sanderling)	WD-NU	?	**	Nests in far north. Winters along Atlantic and down to Argentina. Abundant on Virginia beaches. Rarely enters water, running at edge of surf feeding when waves recede.	Eats *Donax*, *Emerita*, amphipods, and other beach invertebrates.
Ocypode quadrata (ghost crab)	WD-U	? (Perennial)	?	Supralittoral. Enters water to moisten gills or escape predators. Lives in close aggregations. Occurs from Rhode Island to Brazil.	Omnivorous scavenger.
Spisula solidissima (surf clam)	WD-U	17 years (maximum)	17 years	Basis of significant and growing fishery. Important beds south of Long Island and east of New Jersey and Delaware.	Filter feeder.
Amphiporeia virginiana or other haustorids (amphipod)	NWD	Annual	*	May be extremely abundant. Various species may dominate at any given time and place. A different genus (*Ampelisca*) is recovering very slowly at West Falmouth.	Detrital feeder.

TABLE 7.4-17

Sandy Hook - Cape Canaveral:
Marsh Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Spartina spp. *S. alterniflora* *S. patens* (cordgrasses)	NWD	Annual shoots; perennial fillers.	*	Spreads by seed and underground shoot, with local expansion primaily by shoots.	As detritus, it feeds bivalves, amphipods, isopods, crabs, shrimp and more. This and other grasses are important as substrate for epiphytes.
Juncus spp. *J. gerardi* *J. roemerianus* (rushes)	NWD	?	*	Grows at or above high tide, with *J. gerardi* north of Chesapeake Bay and *J. roemerianus* south.	
Modiolus demissus (ribbed mussel)	WD-U	? (Perennial)	?	May become tainted. Occurs in clumps at roots of *Spartina*. Sessile.	Filter feeder, the major food of various birds and mammals (e.g., clapper rails, raccoon). Young are predation - limited; adults are competition-limited.
Orchelium fidicinium (salt marsh grasshopper)	WD-?	Annual	?	Eggs overwinter. Fecundity not known. Adults can locate and recolonize quickly a denuded marsh; few marshes are too isolated for this to occur.	Feeds on living *Spartina*, about 1% of annual production.
Prokelisia marginata (plant hopper)	WD-?	?	?	Abundant in North Carolina marshes. Eggs laid on leaf blades (undergo submergence). Present year-round, peaks from July to November.	Feeds on living *Spartina*, about 6 + % of annual production.
Uca spp. (fiddler crabs) *U. pugnax* *U. pugilator* *U. minax*	WD-U	2 + years	? (2 + years)	Throughout region. Chemical cues important to mating and feeding. Found in mud substrate. Found in sand substrate above water level.	Scavengers.

TABLE 7.4-18

Sandy Hook - Cape Canaveral
Oyster Reef Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Interspecies Effects
Crassostrea virginica (Virginia oyster)	WD-U	4-6 years	4-6 years	Important commercially. Growth apparently affected by many factors (food, silt, currents, temperature). Estuarine. May become tainted.	Filter feeder. Victimized by protozoan diseases and boring snails and sponges.
Urosalpinx cinerea (oyster drill)	NWD	12 years	12 years	Direct development of young throughout region; no dispersal of larvae.	Preys heavily on oysters.
Cliona spp. (oyster voring sponge)	WD-U	?	A few years.	Adult stage exists as an encrusting colony, which is being continuously regenerated. Planktonic larvae.	Completely (slowly) destroys oyster shells on which it grows.
Diadumene leucolena (sea anemone)	WD-U	Perennial	?	May reproduce asexually and sexually.	Oysters are one possible substrate.
Polydora spp. (tubiculous polychaete worms)	WD-U	(Sub)annual	?		*P. websteri* grows on oysters and snails, often at quite high densities (3-282 worms/oyster) as well as on scallops and quahogs.

TABLE 7.4-19

Sandy Hook - Cape Canaveral
Worm and Clam Flat Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Mercenaria mercenaria (quahog or hard clam)	WD-U	6 + years	6 + years	Important commercially in New Jersey, Delaware, Maryland, N. Carolina, S. Carolina, and Virginia. May become tainted.	Filter feeder
Mya arenaria (soft-shell clam)	WD-U	7 years	7 years	Increasingly important commercially in New Jersey, Maryland, and Virginia. May become tainted.	Filter feeder.
Rangia cuneata (bivalve)	WD-U	10 + years	10 years	Brackish water inhabitant. Abundant in suitable areas from Maryland to Florida. May be too far upstream to encounter oil.	Filter feeder.
Diopatra cuprea (polychaete worm)	?	? (Perennial)	?	Tubiculous, mud-sand tube. Cape Cod to Florida.	Tube harbors a micro-community of algae and invertibrates.
Clymenella torquata (bamboo worm)	NWD	? (Perennial)	*	Demersal eggs and larvae; tubiculous adult.*	?

TABLE 7.4-20

Sandy Hook - Cape Canaveral:
Grass Bottom Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Interspecies Effects
Zostera marina (eel grass)	NWD	Shoots annual; roots perennial	* (Depends on whether or not rhizomes are killed.)	Encourages deposition and prevents erosion. Greenland to North Carolina. *Thalassia* replaces it southward. *Zostera* beds required 40 years to recover from a microbial epidemic which struck in the 1930's.	Substrate for many organisms, especially the bay scallop. Subject to protozoal epidemic. As detritus, an important energy source.
Bittium spp. *B. atternatum* (northern) *B. varium* (southern)	NWD	1.5 years	*	No free swimming larval stage. Often abundant.	?
Paracerceis caudata (isopod)	NWD	1.5 years (?)	*	Broods larvae. Overwinters as juveniles. May be abundant.	?
Aequipecten irradians (bay scallop)	WD-U	2 years	2 years	Commercially valuable species.	Disappeared with decline of *Zostera* in 1930's. Still recovering, even after *Zostera* has been reestablished.
Crepidula convexa (slipper shell)	WD-NU (?)	? (Perennial)	?	Aggregates into sedentary piles. Approximately 60 eggs per spawn. Frequency of spawning unknown.	Filter feeder. Lives on *Zostera* blades and hard substrates.

TABLE 7.4-21

Sandy Hook - Cape Canaveral:
Oligohaline Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Interspecies Effects
Spartina cynosuroides (giant cordgrass)	NWD	Shoots are annual; rhizomes are perennial.	* (Depends on whether or not rhizomes are killed.)	High productivity.	Detritus supports abundance of zooplankton and most of food chain.
Rangia cuneata (bivalve)	WD-U	10 + years	10 years	Inhabits brackish water. Abundant in suitable areas from Maryland to Florida. May be too far upstream to encounter oil.	Filter feeder.
Neomysis americana (opossum shrimp)	WD-NU	? (May be less than 1 year)		Broods larvae. Local populations may be very dense, especially on bottom.	Filter feeder. Important food organism for oligohaline fish.

Fish species: *Trinectes maculatus* (hogchoaker), *Micropogon undulatus* (croaker), *Leiostomus xanthurus* (spot), *Cynoscion regalis* (gray trout), *Brevoortia tyrannus* (menhaden), *Morone saxatilis* (striped bass)

TABLE 7.4-22

Sandy Hook - Cape Canaveral:
Medium Salinity Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Callinectes sapidus (blue crab)	WD-U	3 1/2 years	3 1/2 years	Important commercial crab. Migrates between habitats.	Predatory.
Crassostrea virginica (Virginia oyster)	WD-U	4-6 years	4-6 years	Important commercially. Growth apparently affected by many factors (food, silt, currents, temperatures). Estuarine. May become tainted.	Filter feeder. Victimized by protozoan diseases and by boring snails and sponges.
Acartia tonsa (copepod)	Pelagic	(Sub)annual	3-6 months	Reproduces continuously, nonsychronously. Cosmopolitan copepod.	Important grazer of phytoplankton; a crucial link in the food chain.
Chyrsaora quinquecirrha (sea nettle)	WD-U(?)	Annual	1 year(?)		Stings its prey.
Fish species: *Brevoortia tyrannus* (menhaden)					

TABLE 7.4-23

Sandy Hook - Cape Canaveral:
Coastal Habitat

Species (common name)	Recovery Class	Longevity	Implied Recovery Time	Comments	Relevant Inter-species Effects
Spisula solidissima (surf clam)	WD-U	17 years (maximum)	17 years	Basis of a significant and growing fishery. Important beds are south of Long Island and east of New Jersey and Delaware.	Filter feeder.
Penaeus spp. (shrimp)	Pelagic	?	?	Most valuable (in dollars) fishery in U.S. Centered form North Carolina to Florida. Juveniles migrate to inshore nursery grounds, especially marshes and grass beds.	?
Fish species: *Squalus acanthias* (spiny dogfish), *Brevoortia tyrannus* (menhaden), *Stenotomus chrysops* (scup), *Paralichtys dentatus* (summer flounder), *Menticirrhus americanus* (southern kingfish)					

in the recovery time column. Recovery will depend on fecundity and dispersal rates in a manner either not known or, for lack of time, not computed. In addition, the population unit of interest (e.g., breeding population) will affect recovery time, as will intermixing among populations. NWD species such as amphipods, and certain molluscs and worms, are also not assigned recovery times (Section 7.3.4). The symbol * is entered in the tables under recovery time. Recovery of NWD species will depend on expansion rate, fecundity, and extent of kill. Recovery analysis of pelagic species--fish--has been presented in Section 7.5.2 and is therefore not included in the present section.

It is interesting to note that although WD-U species predominate in all habitats in all regions, WD-NU and NWD species also occur in all cases. Given this similarity among habitats and awareness of data uncertainties and inadequate treatment of interspecific considerations, no attempt is made herein to coalesce species recovery times into habitat recovery time estimates and differentiate among habitats accordingly.

7.4.2 Habitat and Regional Differentiation of Vulnerability

A desirable objective of the foregoing arguments and specific physical and biological recovery-time estimates presented in Figure 5.6.1, Tables 7.4-1 to 7.4-23 and Section 7.3.5.2, is to differentiate (inter- and intra-regionally) among habitats according to overall susceptibility to damage from oil spills. If an overall ranking can be made, habitat and ultimately regional vulnerability can theoretically be established by including in the analysis probability of impact from a spill which is a function of probability of a spill and spill trajectories. The question to be considered is: Given the same exposure to oil, do biological differences among habitats provide a basis for distinguishing susceptibility? <u>Based on the analysis presented herein it is concluded that an overall distinction cannot be made</u>. That is not to say that habitats are not, in fact, different in their susceptibility to oil; but only that the available data does not provide any substantive basis for identifying differences. This indistinguishable character holds for both inter- and intra-regional comparisons.

Three bases for differentiation are possible: (1) persistence time; (2) biological recovery; and (3) special characteristics, such as endangered species. Some differentiation based on persistence (Chapter 5) has been made. Oil is likely to persist for longer periods (up to 10 years or more) in unconsolidated sediments than on rocky substrates (2-3 years). In addition, oil is likely to degrade more rapidly in southern regions. However, the previous section (7.4.1) indicates the present inability to differentiate based on biological recovery times. Special characteristics, such as occurrence of endangered species, nursery grounds and spawning areas may allow some measure of biological differentiation among regions. However, insufficient emphasis on collection of this type of data has been made in this study to state with reliability the special feature characteristics of the regions considered and differentiate accordingly. Therefore, rather than attempt to even make a tentative overall habitat ranking, inter- or intra-regionally, it is concluded as most consistent with available data to keep distinctly separate differentiations based on the three factors discussed above.

7.4.3 Gulf of Alaska Regions

Section 4.4 documents the lack of information on the biology of the Gulf of Alaska. Only about twenty species are sufficiently known to be singled out as important. Sufficient life-history information does not exist for even this small group of species to permit description of recovery strategies and analysis of recovery times. Furthermore, a recovery analysis for these species would be of little use for accessing the sensitivity of various stretches of the Gulf coastline because the geographic distribution of these species are largely unknown. Simply too little is known about the biology of the Gulf of Alaska to warrant or permit predicting the recovery times of species or the sensitivities of habitats.

The sensitivities of fish species from this region are discussed in Section 7.3.5.2. Spawning and nursery areas and streams incorporating anadromous fish are identified as the only zones where oil spills might effect whole populations of fish. These potentially sensitive areas are uncharted at present.

The high sensitivity to oil of birds in general is discussed in Section 7.3.3. Birds are particularly important in the Gulf of Alaska region; 200+ species are found along the Gulf of Alaska coast. Many species migrate along the flyway between Alaskan coastal mountain ranges and the seashore (a very narrow strip in places), stopping to rest and feed on coastal marshes like the Copper River delta. The whole populations of some species are known to breed along the coast; in particular, the whole population of the endangered Dusky Canada Goose breeds in the Copper River delta. Species from all over the Pacific return through this area when it gets cold in the southern hemisphere. Critical bird habitats are listed in Table 7.4.3-1.

7.5 Continuous Spill Model

Under present practices, low-boiling fractions of oil may be released in the effluent of platform-mounted oil-water separators. Consequently as much as 50 ppm of oil, primarily soluble components, is continuously discharged from each platform oil-water separator unit. A localized plume--a contaminated surface and subsurface region--will be established whose approximate extent and toxicity can be estimated (MIT Oil Task Force, 1973). If the model of continuous spills as presented in the MIT Georges Bank Study is adopted, then a worst-case situation is 2 square miles of contaminated surface area downstream of the platform, through which waters pass at an average drift of, say, a knot. The dimension of the plume perpendicular to current flow will be small, less than 1/2 mile wide by 50 feet deep, suggesting that a maximum volume of .005 cubic miles of water per hour is exposed to (effective) 100 ppb of low-boiling point hydrocarbons. This is equivalent to approximately 45 cubic miles of water per platform per year (ignoring overlap of pathlines) taking on oil which remains toxic for the length of the water's residence in the plume (about four hours in this simplistic example).

The biological significance of this calculation is not clear. Macrofauna such as fish, squid, and aquatic mammals will supposedly actively avoid the contaminated region (Section 7.3.5.1). Therefore primarily planktonic organisms--phytoplankton, zooplankton, icthyoplankton--and their less mobile predators--arrowworms, shrimp, and so on--may be swept through the stationary discharge plume.

Mortality will undoubtedly occur in the more sensitive larvae and zooplankton populations throughout the region of the plume, and in hardier phy-

TABLE 7.4.3-1[1]

PRIORITIES FOR PRESERVATION OF WATERFOWL NESTING HABITAT[2]

Area	Square Mile	Breeding	Breeding Ducks per Sq. Mile	Other Values	Priority
Yukon Flats	10,800	1,073,000	99	High production--shorebirds, passerine, terns. Moderate--geese,loons, crane.	1-2
Copper Delta	400	34,300	86	Highest production--Dusky Canada geese, trumpeter swan. High value to migrant waterfowl and shorebirds.	1
Tanana-Kusk	9,300	621,800	67	High production--trumpeter swans, cranes, loons, terns, shorebirds, passerines.	2-3
Seward Peninsula	3,850	230,700	60	High value to migrants. Good goose habitat with depleted population of brant, emperor, and Canada geese.	1-2
Innoko	3,400	179,400	53	Moderate production--geese, swans,etc.	2-3
Yukon Delta	26,600	1,273,800	48	Highest production--whistling swans, brant, cackling geese, emperor geese, cranes, loons, shorebirds. High value--migrant snow geese, all others.	1-2-3
Kotzebue Sound	5,350	233,700	44	Good production--whistling swans, white-fronted geese.	2-3
Bristol Bay	9,900	317,500	32	High production--whistling swans.	3
Koyukuk	4,100	132,900	32	Good production--white-fronted geese.	3
Nelchina	3,900	94,000	24	Good production--trumpeter swan.	3
Arctic Slope	23,000	345,966	15	Low production--whistling swans, white-fronted geese, brant, loons, High value for molting geese, migrants of many species.	2-3
Kenai-Susitna	2,200	26,700	12	Good production--trumpeter swans. Depleted population of snow geese. High value for migrant waterfowl, etc.	3

1. From U. of A., 1973.

2. Priorities are assigned on the basis of the value of the habitat unit, the availability of similar habitat, and vulnerability of the habitat or wildlife species it contains. Large units may have areas of different value, as indicated in priority numbers assigned.

BLANK

toplankton and predator species at least in the more concentrated regions of the plume. It is assumed that the ultimate ramification of these deaths to populations will not be severe because only a small fraction of a widely dispersed planktonic population will ever encounter one of the localized permanent plumes. This assumption is an intuitive one only, which considers the limited extent of these stationary plumes relative to the entire offshore coastal area.

Any threat then must be to highly aggregated species, by the placement of a platform and its associated plume in the midst of a critical area such as a breeding ground or an eddy serving as a nursery. Similarly, regions of upwelling commonly support a high concentration of pelagic organisms. Placement of platforms in such regions should therefore be avoided.

An associated but poorly understood process is potential accumulation of oil in sediments in the vicinity of a platform. The extent to which oil builds up in sediments beneath a platform cannot be predicted. However, mechanisms of oil transport to the sediment can be identified. Vertical dispersion due to molecular diffusion will probably not transport significant quantities of oil below five meters (Lassiter, Powers and Devanney, 1974). Strong wave turbulence may drive oil as deep as 80 meters (Forrester, 1971). Probably the most significant surface-to-sediment transport will involve sedimentation--i.e., adsorption of oil onto particulate matter in the watercolumn which settles to the bottom or, in the case of heavier oil fractions, sinks directly of its own weight. In either event the presence of an abrupt pycnocline (change in density with depth, a characteristic of highly stratified waters) may alter settling patterns to some as yet unexplored degree. Adequate experimentation remains a prerequisite to resolution of these processes. As a final point on sediment accumulation of oil it is worth reiterating that the finer the sediments the longer the persistence of incorporated oil (see Chapter 5).

Another potential problem associated with continuous, low-level discharges is potential accumulation of hydrocarbons in lipid pools of marine organisms. Even if populations themselves are not affected, the value of commercially and recreationally important species may be diminished by tainting. Furthermore, accumulations over long time periods may effect populations in presently unknown manners. In any case, these discharges contribute to the overall inputs of hydrocarbons to the ocean and should be restricted as much as possible until subtle effects such as food chain accumulation are better understood.

It is apparent that very little is known about the potential biological impact of offshore oil-water separator effluent. The following two guidelines are proposed to ensure that biological impacts are minimized:

1. Treat the separator effluent to remove soluble hydrocarbons before discharge. This may be accomplished with existing technology but residual wastes may have to be shipped or piped to onshore treatment facilities.
2. If treatment is not possible, and in any case to reduce the menace of a blowout, it is prudent to place platforms in biologically innocuous locations (if such can be identified), far from regions of upwelling (nutrient-rich "oases" of the ocean) or spawning or nursery groudns. And as discussed above, deep water and coarse sediments may be preferable physical attributes of a drilling site.

The foregoing analysis has not referred to Gulf of Mexico drilling experience which has apparently not produced any grave impact from separator wastes. The Gulf of Mexico is a tropical environment, and as such exhibits highly different productivity, nutrient cycling patterns, and competitive strategies among organisms than the more physically controlled temperate and boreal regions of this study. Thus the experience of the Gulf in this respect cannot be extrapolated to the Atlantic coastal region with any degree of confidence.

Until much needed experimentation on the fate and effects of separator effluent in northern waters is initiated, discussion of risks and tradeoffs remains speculation. The desirability of waste treatment under these circumstances is reiterated and field studies encouraged to resolve the uncertainties of this analysis and to update the recommendations.

7.6 References

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APPENDIX 7-1

VARIATION OF AGE-STRUCTURE OVER TIME
A MATHEMATICAL MODEL

An important characteristic of a population is its age-specific survivorship and fecundity schedule. In fact, in the simplest mathematical model of age-specific population growth, all other factors are ignored and these two alone determine population growth and eventual stability. Presented below is an analysis of the relationship between age-specific survivorship and fecundity and time to stable age-distribution, for wide dispersal ubiquitous species.

The Leslie Matrix (Leslie, 1945) approach offers a simple algorithm for calculating the age-distribution at time t from an initial age-distribution at time, t_0, based on age-specific phenomena. Let:

l_x = proportion of the 0^{th} age-class of females surviving to age x

q_x = proportion of females entering age x which die before age x+1

$1-q_x$ = proportion of females entering age x which survive to age x+1

m_x = number of females born per female of age x

n = longevity of the species

$N_x(t)$ = number of females of age x at time t

$\underline{N}(t)$ = vector of age-structure at time t ($N_x(t)$ for x=0 to n-1)

Then the Leslie Matrix $\underline{\underline{L}}$ is defined as

$$\underline{\underline{L}} = \begin{bmatrix} F_0 & F_1 & F_2 & \cdot & \cdot & \cdot & F_{n-1} \\ P_0 & 0 & 0 & \cdot & \cdot & \cdot & 0 \\ 0 & P_1 & 0 & \cdot & \cdot & \cdot & 0 \\ 0 & 0 & P_2 & \cdot & \cdot & \cdot & 0 \\ \cdot & & & & & & \cdot \\ \cdot & & & & & & \cdot \\ \cdot & & & & & & \cdot \\ 0 & \cdot & \cdot & \cdot & \cdot & P_{n-2} & 0 \end{bmatrix}$$

Where $F_x = (1-q_{x-1})\ m_x$ = a measure of fecundity

$P_x = 1-q_x$

The Leslie Matrix has been defined such that

$\underline{N}(t+1) = \underline{L}\ \underline{N}\ (t)$, so that

$\underline{N}\ (t) = (L)^t\ \underline{N}\ (0)$.

A stable age-distribution $\underline{N}$ (t) is defined such that $N_x(t)/N_x(t+1)$ is constant, for all ages x. For computational purposes, stability occurs when all the R_x's are within a given tolerance of each other. With this criterion one determines T_r (= time to stable age-distribution), for a given initial age-distribution, by iteratively calculating $\underline{N}$ (t) and checking all R_x's to see if they are all "close enough" to each other.

To apply this algorithy to WD-U species, a major alteration is made. Age-specific fecundity is deleted (justified below) and is replaced by immigration of larvae in the 0^{th} age-class, bringing the population back up to its carrying capacity K in each time period. The standard Leslie Matrix approach executes the following calculations:

$$\begin{aligned}
N_0(t+1) &= \sum_{x=0}^{n-1} (1-q_{x-1})\ m_x\ N_{x-1}(t) \\
N_1(t+1) &= (1-q_0)\ N_0(t) \\
&\ \vdots \\
N_{n-1}(t+1) &= (1-q_{n-2})\ N_{n-2}(t)
\end{aligned}$$

However, with the definition of a WD-U species, the age-structure of a WD-U species is determined by:

$$\begin{aligned}
N_0(t+1) &= I(t) = K - \sum_{x=0}^{n-1} N_x(t)\ (1-q_x) \\
N_1(t+1) &= (1-q_0)\ N_0(t) \\
&\ \vdots \\
N_{n-1}(t+1) &= (1-q_{n-2})\ N_{n-2}(t)
\end{aligned}$$

Note that for WD-U species, the number of individuals in the 0^{th} age-class is independent of age-specific fecundity, but depends instead on immigration, keeping the population always at its carrying capacity. Because of this difference, the Leslie matrix algorithm must be modified for application to WD-U species.

The modified Leslie Matrix $\underline{\underline{L}}'$ includes an extra row and column:

$$\underline{\underline{L}}' = \begin{bmatrix} 1 & 0 & 0 & . & . & . & 0 & 0 \\ 1 & -P_0 & -P_1 & . & . & . & -P_{n-2} & 0 \\ 0 & P_0 & 0 & . & . & . & . & 0 \\ 0 & 0 & P_1 & . & . & . & . & . \\ . & & & . & & & & . \\ . & & & & . & & & . \\ . & & & & & . & & . \\ 0 & & & & & & P_{n-2} & 0 \end{bmatrix}$$

The modified algorithm also incorporates a modified age-structure vector $\underline{N}$ (t), with one extra element:

$$\underline{N}' = \begin{bmatrix} K \\ N_0 \\ N_1 \\ \vdots \\ N_{n-1} \end{bmatrix}$$

where K = carrying capacity of the environment = maximum density of the population. Using the modified $\underline{\underline{L}}'$ and $\underline{N}'(t)$ in the old algorithm, one can get

$$\underline{N}'\ (t + 1) = \underline{\underline{L}}'\ \underline{N}\ (t), \text{ and}$$
$$\underline{N}^1(t) = (\underline{\underline{L}}^1)^t\ \underline{N}^1(0).$$

The definition of a WD-U species requires that one neglect age-specific fecundity and pre-settlement mortality. Thus, no F_x's appear in $\underline{\underline{L}}$, and the 0^{th} age-class begins at settlement. Also, P_0 equals the survivorship from settlement to one year after settlement; one year after settlement is approximately equal to one year of age, for most species.

The Leslie Matrix algorithm, incorporating $\underline{L}'$ and $\underline{N}'$, can be used to model population growth and age-distribution over time for WD-U species. In order to compare survivorship schedules independent of longevity, dimensionless ages ($\hat{x}$) are used to measure the time increments during recovery:

$$\hat{x} = \% \text{ of total life span, in increments of } 10\%.$$

In the present analysis, stable age-distribution is defined as occurring when all R_x's equal 1 ± 0.1.

The relationships between various hypothetical post-settlement survivorship schedules and time to stable age-distribution have been calculated, and are tabulated in Table 7-1.1. In all cases, the extension of calculated recovery time beyond one life-span is apparently caused by a pseudo- "dominant age-class" phenomenon, prompted by inaccuracies in the model used. The first year's influx of K individuals in one year-class is carried through succeeding age-groups until at $\hat{x} = 100\%$ all of the survivors die. The death of the remainder of the dominant year-class leaves a gap in the population that year, prompting another large, but slightly damped, immigration at age $\hat{x} = 100\%$. In this way the instability of a dominant age-class sometimes continues for several life-spans, delaying recovery up to T_r = (2 or 3) x longevity.

The principal inaccuracies which are responsible for the long recovery times in Table 7-1.1 are: 1) the use of extremely high survivorship rates throughout a species' life span, and 2) the omission of influences which vary a species' survivorship schedule during recovery (see section 7- 3). Few WD-U species (none of the selected species in this study) have survivorship schedules as high as cases #3, 4, 5, and 6 in Table 7-1-1. Furthermore, to a species that did have such a high survivorship, changing inter- and intra-specific factors during recovery will normally act to reduce survivorship as the species approaches recovery. Excluding extreme survivorship schedules, the modified Leslie Matrix algorithm shows then, that for most WD-U species recovery time is approximately equal to longevity.

Table 7-1-1
Time to Stable Age-Distribution for Various
Post-Settlement Survivorship Schedules

Survivorship Schedule												Recovery Time
ℓ[% of life span]:	0	10	20	30	40	50	60	70	80	90	100	
$(1-q_{\ell})$:	.4	.4	.4	.4	.4	.4	.4	.4	.4	.4	0	1.1 x longevity
$(1-q_{\ell})$:	.6	.6	.6	.6	.6	.6	.6	.6	.6	.6	0	1.1 x longevity
$(1-q_{\ell})$:	.8	.8	.8	.8	.8	.8	.8	.8	.8	.8	0	2.1 x longevity
$(1-q_{\ell})$:	.8	.9	.9	.9	.8	.8	.7	.8	.9	.9	0	1.3 x longevity
$(1-q_{\ell})$:	.9	.9	.9	.9	.8	.8	.7	.8	.9	.9	0	3.1 x longevity
	(≈ .85	.85	.85	.85	.8	.8	.8	.8	.8	.8	0)	2.3 x longevity

APPENDIX 7-2

EFFECT OF SIGNIFICANT ADULT MOBILITY ON RECOVERY TIME

The model of recovery of a wide dispersal-ubiquitous species, in Chapter 7, assumes re-population of a killed area by larvae only. However, a few species in the WD-U class have significant adult mobility, permitting immigration of adults directly into the recovery area. For a WD-U species with adult recolonization, recovery time is estimated as:

$$T_r = (0.5 \text{ to } 1.0) \times (\text{longevity}).$$

Adult recolonization acts to hasten recovery by filling the older age-classes before the larval immigrants have aged into those classes. Even a small amount of adult immigration will have this effect; hence, these species are modeled with a maximum recovery time of (1.0 x longevity).

The minimum time to recovery for these species is estimated at 0.5 longevity. The constraint on the lower bound is that the density of each age-class must be uniform over the whole recovering area. The time required to achieve a uniform density, independent of stable age-distribution, is in turn constrained by a species' yearly migration range and by the size of the impacted area (see the preceding model of recovery of NWD species for a more detailed analysis based on these two parameters). The estimated lower bound of 0.5 x longevity is intended only as a best-case value of recovery time, where achieving uniform density is not a constraint.

This model of adult immigration neglects the loss to the surrounding areas of the immigrating adults. It is assumed that such migration is slow enough, and the stock population large enough, that losses due to immigration will not be felt.

CHAPTER 8

ANALYSIS OF SELECTED HYPOTHETICAL OIL BISCHARGES

8.1 Introduction

The principal objective of this study is to assess potential biological effects of hypothetical oil discharges. Given the high levels of uncertainty associated with all aspects of the available data base, no definitive predictions of spill effects can be made. However, rough estimates can be made and, consistent with the previous material presented, a systematic framework for assessing effects is layed out.

Only a small set of selected discharges are considered in detail. However, events other than considered here may be analyzed by the same approach used below, if warranted.

8.2 Accidental Spills Originating from Hypothetical Atlantic OCS Drilling Sites

Accidental spills occurring at drilling platforms may effect the pelagic zone, off-shore bottom habitats and nearshore habitats (e.g., sand shore, rocky shore, salt marsh, etc.). Potential pelagic zone effects have been previously discussed in section 7.3.5. The arguments presented therein are summarized and elaborated appropriately in section 8.2.1. Section 8.2.2 presents a discussion of possible spill effects on offshore bottom habitats. Nearshore effects of platform spills depend upon several factors, especially time to reach shore and distribution of various habitats (due to differences in, primarily, persistence of oil). Therefore, nearshore habitat effects (except fish species) are analyzed in section 8.2.3.

8.2.1 Pelagic Zone Effects (including nearshore fish species)

The primary threats of an oil spill in the pelagic zone are: 1) potential direct effects on eggsand larvae of many fish species; 2) disruption of breeding in certain fish species; and 3) effects on diving birds. As discussed in some detail in section 7.3.5, concern is focused on species which demonstrate a significant degree of localization, particularly during breeding. Widely-dispersed populations with extensive intermingling of adults throughout the pelagic zone are hypothesized to be protected from any detectable effects due to the shear size of the area over which such a population is distributed relative to the size of a spill.

An oil slick moving on the ocean surface can be expected to kill much of the plankton and neuston with which it comes into contact. During the first two days or so **mortality** can result from both toxic effects of lower boiling hydrocarbons still present in the slick and from mechanical coating of organisms with oil. Over longer time periods--throughout the life of the slick--mortality may result from ocating effects.

In offshore regions, because the total area swept by the spill is small relative to the total surface, the expected percent of any plankton population killed will be negligible, except possibly for species with localized "breeding populations" (see section 7.3.5). In this latter case, if a local population exists which does not intermingle with individuals of the same species from other areas, then the area swept by a spill may be large relative to the area inhabited by the local population, resulting in a kill of a significant percentage of the population. Recovery in such a situation will depend on the degree of isolation of the local population as well as other factors normally effecting the recovery process (section 7.3). Arrowworms (Sagitta elegans) are the only zooplankton species identified at this time as exhibiting any degree of localization. For most zooplankters (copepods, cladocerans, etc.) data is not available which indicates whether or not any significant localization exists. However, probably all plankters demonstrate unpredictable localized aggregations--and may be temporarily affected. In any case virtually all zooplankton species live one year or less and have high fecundities, indicating that the effects of a spill will be undetectable within a year or much less.

Except for anadromous fish species, which may be threatened by a spill occurring nearshore which could interrupt a spawning run, kill migrating adults, or contaminate breeding grounds no fish species examined appears seriously threatened based on the assumptions and analysis presented in section 7.3.5.2. Beyond expressing concern for a threat to a species, it is not possible with the available data to make any prediction of the potential effect a particular spill moving into an estuary may have on anadromous species occurring in each of the regions. However, as shown in section 8.2.3 hypothetical oil spills occurring at proposed drilling sites in the Southern Atlantic (EDS 10, 11, 12, and 13) may find their way into estuarine subsystems. Hypothetical spills occurring in the Middle Atlantic (EDS 5, 6, 7, 8 and 9) are less likely to be transported with any integrity as a slick into estuarine waters. Also, as indicated in Figure 7.3.5-3, the Middle Atlantic region may be less important as an offshore spawning ground than other areas. Finally, although spills originating at drilling sites on the Georges Bank have apparently no chance of finding their way into estuaries, the importance of these offshore waters as a spawning and nursery ground must be recognized.

A final problem to be considered relative to the effects on the pelagic zone of hypothetical spills is effects on birds. In general, bird species constitute one of the most vulnerable populations to catastrophic mortalities (see section 7.3.3). However, insufficient information is available for this study (although some relevant data may exist) to identify specific effects resulting from particular spills hypothesized for specific spills (see section 7.3.3).

8.2.2 Offshore Bottom Effects

Offshore bottom habitats may be exposed to oil as a result of sedimentation of oil or other processes which transport oil vertically downward in the water column. These processes are not well enough understood to predict the amount or composition of oil that may reach bottom sediments at various depths. Data collected by Forrester (1971) following the spill from the Tanker Arrow indicate that little or no oil may be transported to depths below 100 meters. However, significant amounts of oil from the Santa Barbara spill were deposited in offshore bottom sediments because of high concentrations of suspended sediment in the region of the spill (Kolpack, 1971). In general, crude oil that is transported into offshore (water depths exceeding 50 meters) bottom sediments can be expected to have lost a large percentage of the lower boiling, toxic hydrocarbons during the sedimentation process. In addition, the oil is likely to be well dispersed so that coating effects are unlikely to be significant. The most important effect likely to occur is the possible alteration of sediment characteristics, possibly making areas effected unsuited for certain normally found species. Such effects may persist for 2-3 years in sandy bottoms, longer in sediments containing significant amounts of silt or mud and indeterminately long if sediments are anaerobic (see Chapter 6). In general, the sediments of the offshore bottoms throughout the Atlantic OCS are gravelly or sandy, although significant muddy areas do occur, especially on Georges Bank. More specific predictions of the effects in these offshore bottom areas cannot be made without better knowledge of the amount and composition of oil which may be transported into the sediments.

8.2.3 Nearshore Habitat Effects

Nearshore habitat effects of spills originating offshore are summarized in Table 8.2.3-1 for specific spill scenarios associated with each hypothetical drilling site. The meaning of each column in the Table is explained below.

Spill scenarios are described by several parameters:

EDS - hypothesized drilling site number (see Chapter 2). Only spills originating from the center of the drilling site location are considered.

Time to Shore - minimum and average times in days calculated for spills in specified season of the year to reach shore (Stewart, Devanney and Briggs, 1974).

Season - season of the year yielding "worst case" condition in terms of shortest time to shore and highest probability of coming ashore.

Most Likely Impact Zone - coastal region in which spill is most likely to come ashore. A single spill would impact only a portion of the area within the specified region.

% of Spills Ashore in Zone - according to the analyses by Stewart and Briggs (1974) the percentage of 200 hypothetical spills which come ashore somewhere within the zone.

The impact for each scenario is described by:

Oil Composition - unweathered (contains sufficient lower boiling, hydrocarbons to cause toxic responses), weathered (lower boiling, hydrocarbon concentration too low to cause any significant toxic response), very weathered (only tarry, residual petroleum substance remains).

Oil Amount - an estimate of the "slick" form and size which may come ashore. Patch size depends on volume and rate of spilled oil release.

Coverage - estimate of extent of impact zone effected by single spill. Size of "subarea" associated with particular spill depends on volume spilled.

Habitats Exposed - habitats, as defined in Chapter 4 and discussed in Chapter 7 which are found in impact zone and are expected to be exposed to oil.

TABLE 8.2.3-1 Hypothetical Atlantic OCS Spill Scenarios and estimated nearshore biological effects. See text for explanation.

DRILLING SITE SPILL SCENARIO						NEARSHORE IMPACT DESCRIPTION				INITIAL BIOLOGICAL EFFECTS				RECOVERY	
EDS	TIME TO SHORE (days) MIN	AVE	SEASON	MOST LIKELY IMPACT ZONE	% OF SPILLS ASHORE IN ZONE	OIL COMPOS.	OIL AMOUNT	COVERAGE	HABITATS EXPOSED TO OIL	LETHAL & SUB-LETHAL TOXICITY	INCORPORATION	COATING & HABITAT ALTERATION	ESTIMATED POPULATION MORTALITY WITHIN A HABITAT	RESIDENCE TIME	BIOLOGICAL
4	43	90-100	Spring	Nantucket Is., Martha's Vineyard, S. Coast Cape Cod	17	Very Weathered	Tar Balls and small Patches	Uneven, widely scattered throughout impact zone	Primarily sandy/rocky shores, possibly salt ponds	None	?	Intertidal, sessile species; e.g., barnacles, tide pool inhabitants, mussels, sand dollars, no plants susceptible to mortality by direct coating	immeasurably small	3-5 yr. Minimum	Not applicable (no measurable population effect)
5	7	30-50	Spring-Summer	Cape May (S. New Jersey Coast) to Western L. I.	60-75	Weathered	Patches 1-100 Acres in size	High Energy Beach- Even distribution within subarea of impact zone. Estuarine subsystem occasional patches which are carried past barrier beaches.	High energy beach, May enter inlets into oligohaline, grassy bottom and migrating subsystems (Estuarine subsystem)	None	?	High energy beach - little or no mortality alteration of sandy substrate where oil patches deposited. Estuarine subsystem - intertidal species susceptible to mortality, especially intertidal grasses, e.g. eel grass	immeasurably small	2-3 yr.	Not applicable
6	39	90-100	Spring	Chincoteague Bay (Maryland Atlantic Coast) to Sandy Hook, N.J.	39	Very Weathered	Tar Balls and small Patches	Uneven, widely scattered over large area of impact zone	High energy beach	None	?	Little or no coating mortality; scattered tar balls in sandy substrates	none	2-3 yr.	Not applicable
7	28	50-60	Summer	Chincoteague Bay to Barnegat Bay, N.J.	28	Very Weathered	Tar Balls and small patches	Uneven, widely scattered over large area of impact zone	High energy beach	None	?	Little or no coating mortality; scattered tar balls in sandy substrates	none	2-3 yr.	Not applicable
8	73	100-110	Spring	Chincoteague Bay to Barnegat Bay, N.J.	10	Very Weathered	"	"	High energy beach	None	?	Little or no coating mortality; scattered tar balls in sandy substrates	none	2-3 yr.	Not applicable
9	Virtually no nearshore impact														
10	5	30-40	Spring	Cape Romain, S.C., to Cape Fear, N.C.	95	Weathered	Patches 1-100 Acres in size	Even distribution within subarea of impact zone. Occasional patch may enter estuarine subsystem	High energy beach, estuarine subsystems, neutral embayment (Cape Romain)	None	?	High energy beach - little or no mortality, some alteration of sandy substrate, Neutral embayment - ? Estuarine Subsystems - intertidal species susceptible to coating especially grasses.	immeasurably small	2-3 yr. minimum	Not applicable
11	7	30-50	Spring-Summer	Port Royal Sound, S.C. to Cape Romain, S.C.	70-99	Weathered	Patches 1-100 Acres in size	Even distribution within subarea of impact zone, including estuarine areas	High energy beach, estuarine subsystems, oyster reefs neutral embayment (Cape Romain)	None	?	Cape Romain area should be given more detailed study	immeasurably small	2-3 yr. minimum	Not applicable
12	19	50-60	Summer	Daytona Beach, Fla. to Savannah, Ga.	85-90	Very Weathered	Patches	Widely scattered over large areas of impact zone	Estuarine subsystems, worm and clam flats, high energy beaches	None	?	Little or no coating mortality; oil deposited on sandy and muddy substrates will cause local alteration of habitat.	immeasurably small	2-3 yr. in high energy beach; 4-5 yr. minimum in soft bottoms	Not applicable
13	49	70	Summer	Cape Canaveral, Fla. to St. Augustine, Fla.	100	Very Weathered	Patches	Widely scattered over impact zone	High energy beach	None	?	Little or no coating mortality, scattered tar balls in sand	immeasurably small	2-3 yr.	Not applicable

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The initial biological effects of the impact scenario are described by (see Chapter 6 and 7)

Lethal and Sub-lethal Toxicity - estimated extent of these effects on individuals in each habitat exposed.

Incorporation - the extent to which hydrocarbons may become incorporated in various organisms.

Coating and Habitat Alteration - estimate of extent of these effects.

Estimated Population Mortality - estimate of percent of any population killed by above effects.

Finally, recovery from these effects are described in terms of residence time of oil in the habitats exposed and approximate time for populations and communities effected to recover.

As is evident from Table 8.2.3-1 none of the hypothesized spill scenarios are expected to cause significant biological damage to nearshore habitats. This result is principally due to the fact that all spills considered originate far offshore.

8.3 Accidental Spills Originating from Hypothetical Gulf of Alaska Drilling Sites

Nine drilling sites are proposed in the Gulf of Alaska (see Chapter 2). Hypothetical spills under different current conditions (Stewart and Briggs, 1974) (no current or counterclockwise gyre) are considered in the in the same manner as described in section 8.2. Hypothetical releases causing worst damage (shortest time to shore and/or highest probability of hitting shore) are given in Table 8.3-1 which is analogous to Table 8.2.3-1. Note that only worst case results are shown. Other current season spill scenarios (Stewart, Devanney and Briggs, 1974) also show high probabilities of oil coming ashore, but not as high as those listed. Drill sites 2-6 yield very high probabilities of oil beaching, due in most to their proximity to shore.

The stretch of shore impacted most frequently by drill sites 2-6 is the vicinity of Cape St. Elias. The most notable biological feature in this region is the marshland of the Copper River Delta, an extensive feeding ground for birds on the Pacific Flyway, and the only known habitat for the Dusky Canada Goose. Approximately 200 species of birds pass through or live permanently in this marsh each year.

The probably widespread coating of shorebirds along the eastern Gulf of Alaska coast is the only clear-cut biological impact which can

TABLE 8.3-1

Nearshore Biological Effects of Hypothetical Gulf of Alaska Oil Spill Scenarios. See text for discussion. (Table continued next page.)

DRILLING SITE SPILL SCENARIO						NEARSHORE IMPACT DESCRIPTION			
ADS	TIME TO SHORE (days) MIN	TIME TO SHORE (days) AVE	SEASON	MOST LIKELY IMPACT ZONE	% OF SPILLS ASHORE IN ZONE	OIL COMPOS.	OIL AMOUNT	COVERAGE	HABITATS EXPOSED TO OIL
-2- W.O. Gyre	10	23	Spring	Cape St. Elias to Icy Cape	95	Weathered	Patches 1-100 Acres	Uneven, widely scattered over impact zone	Undetermined. Probably rocky coast and sandy shore
-2- W. Gyre	9	27	Summer	Cape St. Elias to Icy Cape	97	"	"	"	"
-3- W.O. Gyre	3	10-18	All Seasons	Cape St. Elias to Icy Cape	31-84	Slightly weathered to weathered	Patches 1 to 500 acres	Even distribution and wide	Undetermined. Probably rocky coast and sandy shore
-3- W. Gyre	3	7-17	All seasons	Cape St. Elias to Icy Cape and Southern Kenai Peninsula	60-80	Slightly weathered to weathered	Patches 1 to 500 acres	Even distribution and wide	"
-4- W.O. Gyre	7	24	Summer	Montague Is. and Hincin Brook Island to Katalla	91	Weathered	Patches 1 to 100 acres	Uneven, widely scattered	Undetermined. Probably marsh, sandy shore, mud flat, and rocky coast
-4- W. Gyre	7	15	Autumn	Hincin Brook Is. to Katalla. Montague Is. seaward, and Southern Kenai Peninsula	88	Weathered	Patches 1 to 100 acres	Uneven, widely scattered	Undetermined. Probably rocky coast
-5- W.O. Gyre	6	25	Autumn	Southern Kenai Peninsula, seward, and Montague Is.	84	Weathered	Patches 1 to 100 acres	Uneven, widely scattered	Undetermined. Probably rocky coast
-5- W. Gyre	6	24	Autumn	Southern Kenai Peninsula, seward, and Montague Is.	84	Weathered	Patches 1 to 100 acres	Uneven, widely scattered	Undetermined. Probably rocky coast
-6- W.O. Gyre	5	16	Autumn	Southern Kenai Peninsula, seward, and Montague Is.	84	Weathered	Patches 1 to 100 acres	Uneven, widely scattered	Undetermined. Probably rocky coast
-6- W. Gyre	5	21	Spring	Southern Kenai Peninsula, seward, and Montague Is.	83	Weathered	Patches 1 to 100 acres	"	"

Table 8.3-1 (continued)

ADS	INITIAL BIOLOGICAL EFFECTS				RECOVERY	
	LETHAL & SUB-LETHAL TOXICITY	INCORPORATION	COATING & HABITAT ALTERATION	ESTIMATED POPULATION MORTALITY WITHIN A HABITAT	RESIDENCE TIME	BIOLOGICAL
-2- W.O. Gyre	None	?	Birds with probably high mortality; e.g., Dusky Canada Geese, Trumpeter Swan. (Pacific Bird Migration Flyway)	Severe for birds. Undeterminable for other organisms	?	?
-2- W. Gyre	None	?			?	?
-3- W.O. Gyre	Possible to Dungness & Tanner Crabs	?			?	?
-3- W. Gyre	"	?			?	?
-4- W.O. Gyre	None	?	Birds, especially, because of significant and unique nesting area in Copper Delta. Possible coating of Dungness and Tanner Crabs, and Razor clams.		?	?
-4- W. Gyre	None	?			?	?
-5- W.O. Gyre	None	?			?	?
-5- W. Gyre	None	?			?	?
-6- W.O. Gyre		?			?	?
-6- W. Gyre		?			?	?

be discerned from the scarce data available. Other potential biological effects cannot be identified nor dismissed from available biological information.

Spill trajectory information provides one possible basis for a decision. Drill sites 7-9, because of lower probability of spills coming ashore and because of less danger to shorebirds, are preferable to sites 1-6. However, this is not to say that problems do not exist for sites 7-9, or that other environmental risks, not obvious due to the lack of data, are not present for sites 1-6. The critical lack of data on the area makes this whole analysis speculative at best.

8.4 Accidental Spills Originating at Terminals

Oil spills resulting from OCS petroleum developments can occur near shore from tanker, barges and/or pipelines, as well as offshore platforsm. An innumerable number of hypothetical near shore events can be postulated, each spill scenario having different characteristics. Examples considered herein follow from the three specific hypothetical terminal sites identified by CEQ (Chapter 2); Buzzards Bay, Delaware Bay, and Charleston Harbor.

Stewart, Devanney and Briggs (1974) have reported spill trajectory characteristics for hypothetical spills at each of these sites. Their analysis focuses on time to shore for a spill and the percentage of initial impacts on a specified shoreline area. In all three situations there is a significant chance of oil coming ashore within 1-2 days, causing impact of unweathered oil on intertidal areas. At each site specific location of spill release and time of year alter the impact site, the time to shore and probability of coming ashore.

At Buzzards Bay 75-90% of all hypothetical spills released near West Falmouth comes ashore within 30 hours. Fifty percent of hypothetical winter spills released at the entrance to New Bedford channel come ashore in 40 hours. Hypothetical spills released in central Delaware Bay have somewhat higher times to shore. Approximately 30% of all hypothetical spills released reach shore in 50 hours. Similar results obtain for spills released at the mouth of Delaware Bay. Probability of coming ashore is higher and time to shore is lower for spills released in Charleston Harbor. Typical times to shore are 10 hours or less and virtually all hypothetical spills released come ashore in 30 hours or less.

Although the foregoing results indicate variations among the sample terminal locations, the essential conclusion is that in all cases there is a relatively high probability of an unweathered oil spill impacting the shoreline. In general, the result of such an event, independent of the specific zone of impact, will be high mortality of individuals in most phyla and heaving coating of intertidal substrates. Recovery--physically and biologically--would be many years, at best, depending in part on the type of substrates coated. The effects of the West Falmouth spill of #2 fuel oil (Sanders et al., 1972; Blumer et al., 1972) are typical of what can be expected from near shore spills, even spills of crude oil. As discussed in Chapters 5 and 6 unweathered crude oil contains sufficient low boiling aromatics to cause toxic responses in most marine species. In fact, crude oil can be expected to persist even longer than #2 fuel oil, as in the West Falmouth case, because of a large residual fraction absent in #2 fuel oil.

More specific treatment of nearshore spills is not given here for two reasons. First, the environmental inventories (Chapter 4) were not designed to provide the level of detail necessary to capture specific descriptions of the three terminal areas considered. Secondly, given the results of Chapters 6 and 7, a more detailed level of analysis is not warranted because of uncertainties in the effects of oil and recovery processes.

8.5 References

Forrester W.D. (1971) "Distribution of Suspended Oil Particles Following the Grounding of the Tanker Arrow", J. Mar. Res., 29 (2):151-170.

Kolpack R.L. (ed.) (1971) Biological and Oceanographical Survey of the Santa Barbara Channel Oil Spill 1969-1970, Volume II, Physical, Chemical and Geological Studies, Allan Hancock Foundation, University of Southern California.

Stewart R.J., Devanney J.W., and Briggs W. (1974) Oil Spill Trajectory Studies for Atlantic Coast and Gulf of Alaska report to Council on Environmental Quality, Washington, D.C., March 1, 1974, Department of Ocean Engineering, MIT, Cambridge, Massachusetts.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS FOR RESEARCH

9.1 Conclusions

1. The available data does not allow a differention among habitats, intra- or inter- regionally, based on biological recovery time differences from an oil spill causing 100% mortality within a habitat. Such differences may exist, but cannot be identified by the methods used herein. Differences may be identifiable in terms of biological characteristics particularly valued by man, e.g., commercial fisheries.

2. The persistence of oil resulting from impact of the main body of a spill in marine substrates varies from a minimum of 2-3 years on rocky shores to a minimum of 5-10 years in fine, unconsolidated sediments. Oil in the same habitat type can be expected to persist longer in more northern regions. But the magnitude of the difference between northern and southern regions cannot be estimated.

3. Biological recovery of habitats in which 100% mortality occurs, after degradation of oil allows recolonization, can only be estimated as "several years". Aggregation of estimated selected species recovery times to a reliable estimate of habitat recovery time, and ultimately regional vulnerability, is not possible given the available data.

4. In general, fish populations do not appear to be threatened by mortality resulting from oil spills. Anadromous species, such as alewives, striped bass and salmon, may be threatened by nearshore spills which could interrupt spawning migrations or disrupt localized breeding. Although a significant threat to many species cannot be identified, significant uncertainty exists, especially relative to sub-lethal effects. Accordingly, spawning grounds and larval nursery areas are considered more vulnerable than other regions, all else being equal.

5. Birds, as many researchers have suggested and as observations imply, appear to be one of the most vulnerable group of populations examined. The life histories of most avian species dictate that recovery from unusual adult mortality is a long and difficult process. In addition, individual birds are extremely vulnerable to death from oil slicks. No region has been identified as more or less important relative to bird populations.

6. Spills originating from hypothetical Atlantic offshore platforms are not expected to cause severe biological damage. In most cases, drilling sites are sufficiently offshore to alleviate potential nearshore problems. The primary effect expected is localized deposition of weathered patches of oil or tar balls on rocky or sandy shores. Where deposited such oil may persist for two years or more. Population mortalities would be immeasurably small. For certain southern-most sites the probability of significant nearshore biological damage is higher.

7. Based on lower probability of a spill coming ashore and longer time to arrive on shore, hypothetical drilling sites EDS 6, 7, 8, 9 off the New Jersey Coast and sites EDS 1, 2, 3 and 4 on the Georges Bank are preferred over sites EDS 10, 11, 12 and 13 off the coast of Florida and EDS 5 south of Long Island.

8. Spills originating at nearshore terminals which come ashore within 1-2 days can be expected to cause extensive initial mortality in all exposed habitats and require many years for physical, chemical and biological recovery. None of the nearshore terminals examined are free from this potential result.

9. Little can be said about the biological effects of oil spills occurring in the Gulf of Alaska. Habitats cannot be identified and described nor is much known concerning distributions of substrate type or populations. As a result, even if spill scenarios can be hypothesized, the exposed populations are not known, much less potential effects on these populations.

10. The biological significance of continuous discharges from oil-water separators, or other sources of chronic discharges of hydrocarbons, remains obscure. However, until more definitive analysis can be made, discharges of this type should be closely regulated. Concentrations exceeding 0.1-1.0 ppm soluble aromatics are likely to have lethal effects on the most sensitive individuals. Population consequences cannot be evaluated.

11. Two concepts relied on extensively in this analysis appear to be more broadly applicable to environmental impact analysis. First, discretization of large environmental regions into habitats is useful for obtaining some measure of the distribution of both physical and biological variables. Secondly, identification of recovery strategies is a first

step towards an ecological basis for assessing vulnerability of various species to environmental changes. The utility of this approach derives from explicit consideration of life history phenomena. However, extensive efforts remain to refine and validate this utility of this approach.

12. Large levels of uncertainty exist in all phases of the analysis. Insufficient baseline data exists for all regions. Compilation of this data will require above all, time. Many biological phenomena, such as life histories, simply require many years to be observed. Therefore, carefully designed baseline biological studies should be initiated at the earliest possible data. However, significant effort should be made to ensure proper design of such monitoring program. At the present time little is known about how to design "proper" monitoring programs, i.e., where, when, what and how to sample.

9.2 Recommended Research

The lack of data, repeated to the point of boredom throughout this report, indicates the need for extensive research. The list of recommended research topics below is intended to highlight only those areas which the authors believe deserve priority consideration. Both pure and applied research is needed. Many of the recommended research topics are long-term efforts, which cannot be expected to be solvable by 1, 2 or 3 years study--decades may be required in some cases.

1. Investigation of petroleum degradation processes and determination of weathering rates as a function of temperature, light, nutrient concentrations, etc.

2. Investigation of the physical/chemical relationships between oil hydrocarbons and sediment materials. Particular attention should be given to sedimentation processes transporting hydrocarbons into bottom sediments, and to the effect of sediment on degradation of low-boiling aromatic fractions.

3. Studies of oil content of sediments and suitability of sediments for habitation by a wide spectrum of species. In addition, the role of oil composition on sediment suitability should be investigated.

4. Identification of specific hydrocarbons causing toxic effects. All bioassay investigations should be coupled with analytical chemical studies.

5. Investigation of adaptations of organisms to oil exposures, including genetic changes.

6. Basic studies of population life histories for many species are needed. Studies should include identification of survivorship, fecundity, larval life style, migrations, behavior, etc.

7. Careful investigation of community successions at the species level should be undertaken following actual pollution incidents <u>and</u> in controlled, experimental situations.

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